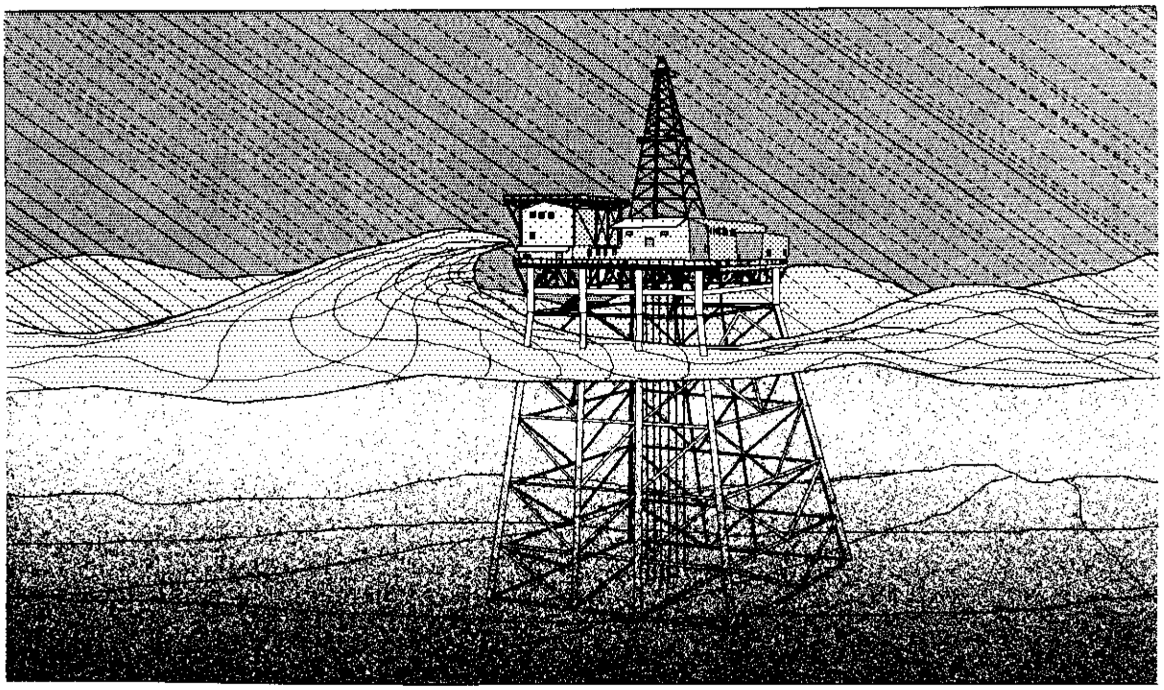
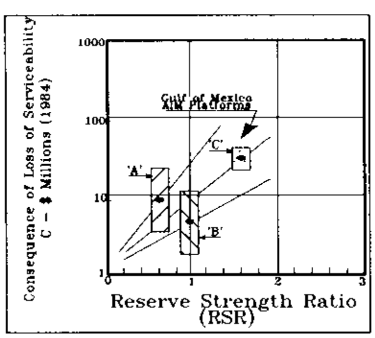
A - I - M

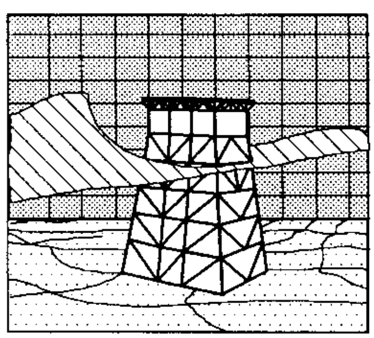
ASSESSMENT INSPECTION MAINTENANCE

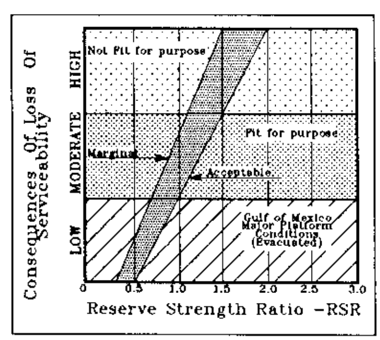
PHASE III

– FINAL REPORTS –









PMB ENGINEERING

SEPTEMBER 1988

CONFIDENTIAL

AIM III FINAL REPORTS

EXECUTIVE SUMMARY

BY

PMB SYSTEMS ENGINEERING INC.

SAN FRANCISCO, CA

SEPTEMBER 1988

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1.0 INTRODUCTION

This report summarizes the results of the third Phase of the AIM (Assess, Maintenance, Inspection) Joint Industry Projects. The AIM process provides the operator with a practical approach to handle basic problems associated with requalifying existing offshore platforms. The AIM projects have developed this approach by developing general guidelines, focusing on key issues and demonstrating the approach on example platform systems.

The AIM-I project outlined a general engineering approach to requalifying platforms. The approach emphasized the need to keep platforms in service, incrementally establishing their safety at the lowest possible cost. The process incorporates procedures from many disciplines such as reliability, structural analysis, environmental mechanics, platform inspection and repair, and political/social issues. All of these and several other concerns must be weighed and balanced to determine an optimum program for keeping a platform in service in a safe and economic fashion.

The AIM-II project demonstrated the practicality of the AIM approach by applying the approach to two low-consequence (demanned, low pollution potential) platforms that have been in service for over 25 years. The problems inherent in these platforms, such as damaged members, outdated original design criteria, decks subject to wave impact, and a 5 to 10 year remaining service life are typical of many early generation platforms reaching the end of their original service life.

Based on the results of the AIM I and II studies, the participants suggested three areas for further development in the next phase of study. These areas became the key tasks of the AIM III project and are briefly summarized as follows:

1. **Intact/Damaged Condition Assessments:** A typical Gulf of Mexico drilling and production platform was selected and analyzed for a variety of typical damage conditions. Examples are bent and dented braces and severe corrosion. The "capacity" of this platform in the damaged condition was compared to the capacity in an intact condition to determine the effect of the damage. The intent is to begin a data base of potential damage conditions and their effect on capacity that will allow an operator to make an estimate of platform capacity should one of these typical damage conditions occur.

2. **Consequences of Platform Failures Data Base:** The realistic estimate of the potential consequences of a platform failure is an important ingredient to the AIM process. Following the AIM II study, there was some concern that the consequence scenarios developed for the project's example platforms had little basis and relied too heavily on conjecture. In an attempt to provide some objective starting point for estimating failure consequences, this task gathered data related to the consequences of past platform failures in the Gulf of Mexico and itemized the information in a comprehensive data base. A total of 42 platform failures or severe damage where included in the final data base.

3. **AIM Evaluation Guidelines**: The AIM II project used a simplified approach for determining the optimum programs for continued service of the two example platforms. The participants felt that the evaluation procedure is a key aspect of the AIM process, and further development was warranted. In particular, the evaluation process should focus on issues not generally covered by the previous AIM such as "high consequence" concerns (injuries, pollution) and public-regulatory aspects.

Since each of these tasks deals with somewhat independent topics, they were completed on an individual basis and documented in separate final reports. Information was transferred between the tasks were required. All three of the final reports are contained in this one volume, with each report containing its own table of contents and section headings. The following sections briefly summarize the results and conclusions of each task.

2.0 DAMAGE CONDITION ASSESSMENTS

A 270-ft water depth platform located offshore Louisiana was used for the evaluation. The platform was identified as Platform "C" (carrying on with the AIM II project terminology which investigated Platforms "A" and "B"). The platform is a self contained, drilling/production unit, with eight legs and twenty four well slots. The platform was designed in 1968-1969 and installed in 1970.

The platform was first analyzed for the intact (as-designed) condition using a sophisticated computer code that mimics the nonlinear response of the platform's members. This process provided an estimate of the platform's ULS (ultimate limit state) capacity, at which the platform can no longer resist environmental or topsides loading. For the intact condition, the platform's capacity, measured as the reserve strength ratio (RSR = platform capacity/100 year design load), was about 1.5.

The platform computer model was then revised to reflect the change in strength associated with series of typical damage conditions. The general nature of these damage cases and their effect on the platform's intact capacity are as follows (Figure 2-1):

Damaged Members Near Waterline: Bent and dented members caused by workboat impacts. Platform capacity dropped by about 5 to 15 percent depending primarily upon the number of damaged members.

Damage Near Base of Jacket: Completely severed members caused by dropped objects from topside operations. Platform capacity dropped by about 10 to 12 percent.

Interior Horizontal Damage with Diagonal Damage: Missing interior horizontals and a damaged transverse diagonal near the platform's midpoint. Platform capacity dropped by about 20 percent. The damaged diagonal contributed to most of capacity reduction.

Corrosion Damage: This case considered overall platform corrosion and localized corrosion in the splash zone. The overall corrosion was the worst damage case considered, resulting in a 35 percent drop in capacity. The localized corrosion case resulted in a 20 percent drop in capacity.

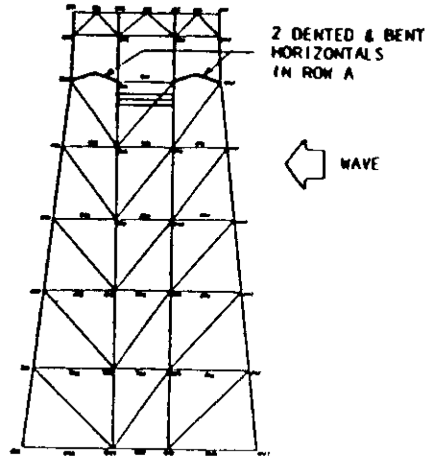
Foundation Defects: Two piles on one of the end transverse bays were considered to be underdriven by 120 feet (out of 270 ft). The capacity dropped from 5 to 17 percent depending upon loading direction.

An additional condition was studied concerning a refined procedure for evaluating wave forces acting on decks. In this case there was no comparison with intact capacity; rather, a refined procedure was outlined for determining wave forces acting on decks. This is an important consideration for older platforms, generally mid-1960's, that were designed according to early generation wave criteria that underestimated design wave heights. The accurate determination of these large deck forces is an important consideration for reliable AIM evaluations.

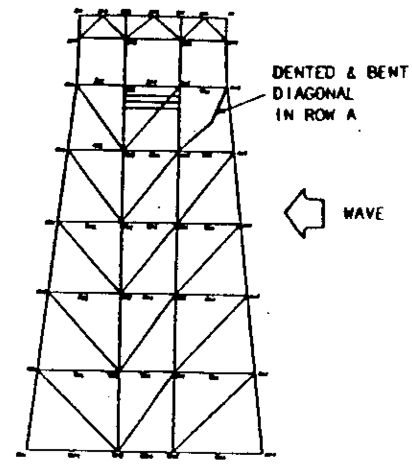
The general response of the platform for the damaged conditions is shown in Figures 2-2 and 2-3. The platform's performance is measured as a function of the applied horizontal environmental load and the deck displacement. Deck displacements at collapse are about twice the first yield displacements. The platform responds in an elastic-plastic fashion due primarily to the K-brace framing.

Most of the damage cases had a minimal effect on the platform's capacity. The one exception is the overall corrosion condition which reduced platform capacity by over one-third. This is expected since virtually every member in the platform has a reduced cross section and hence lower strength. The RSR for this case is slightly less than 1.0, indicating the corroded platform may not survive a 100-year return interval storm.

These damage case studies provide the beginning of a "damaged condition" library for offshore platforms. The information can be used to make an initial assessment of the effect of a particular type of damage on platform capacity. This can be a useful tool for justifying decisions regarding platform inspection and repairs. Other future studies may extend this data base by using different types of platforms and different types of damage conditions.



Case 1



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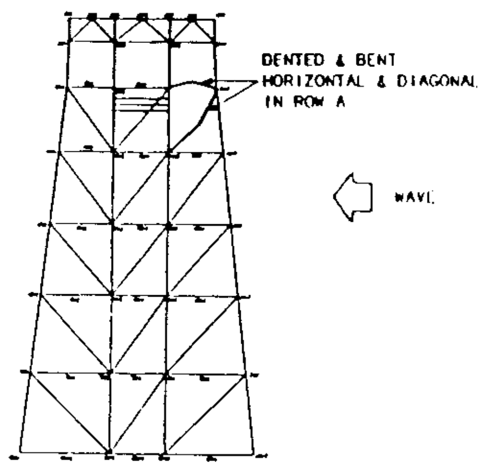
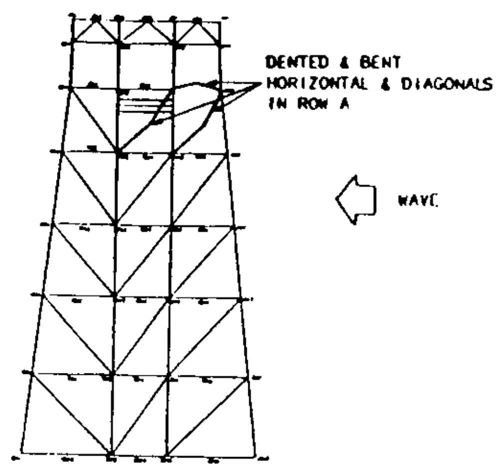
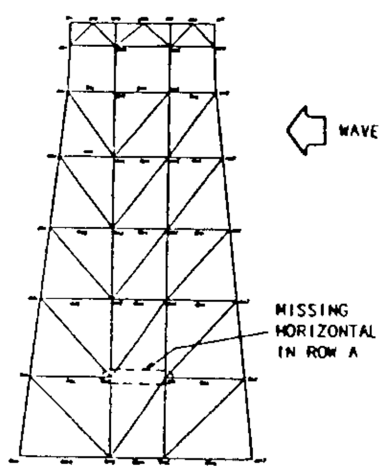


Case 3

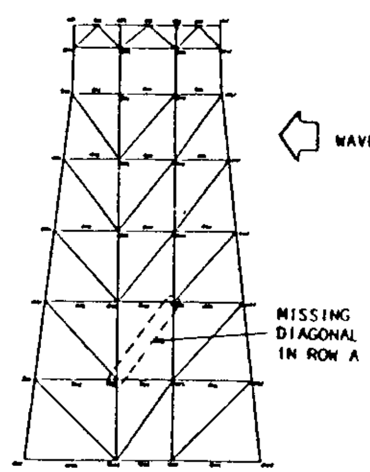


Case 4

DAMAGED MEMBERS NEAR WATERLINE



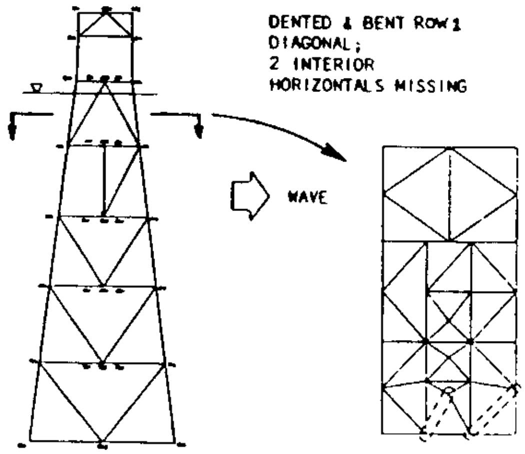
Case 1



Case 2

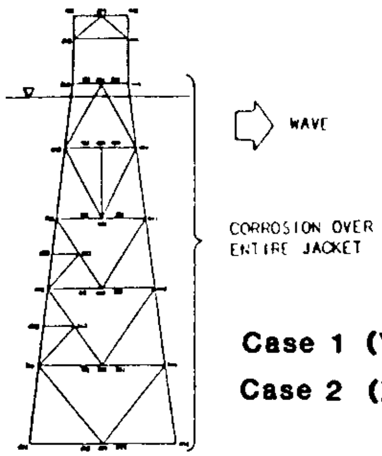
DAMAGED MEMBERS NEAR BASE OF JACKET

FIGURE 2-1 SUMMARY OF DAMAGED CASES

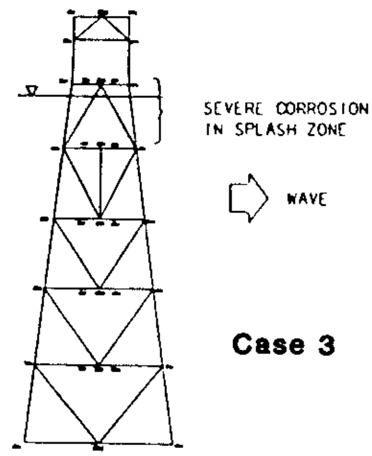


Case 1

INTERIOR HORIZONTAL DAMAGE

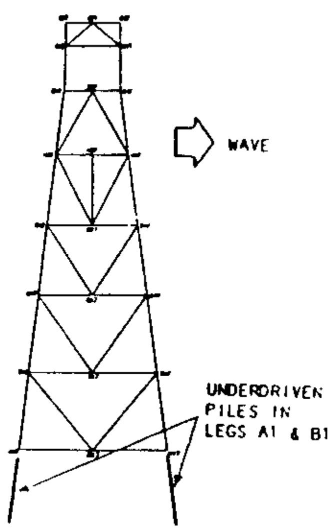


Case 1 (Y Wave)
Case 2 (X Wave)



Case 3

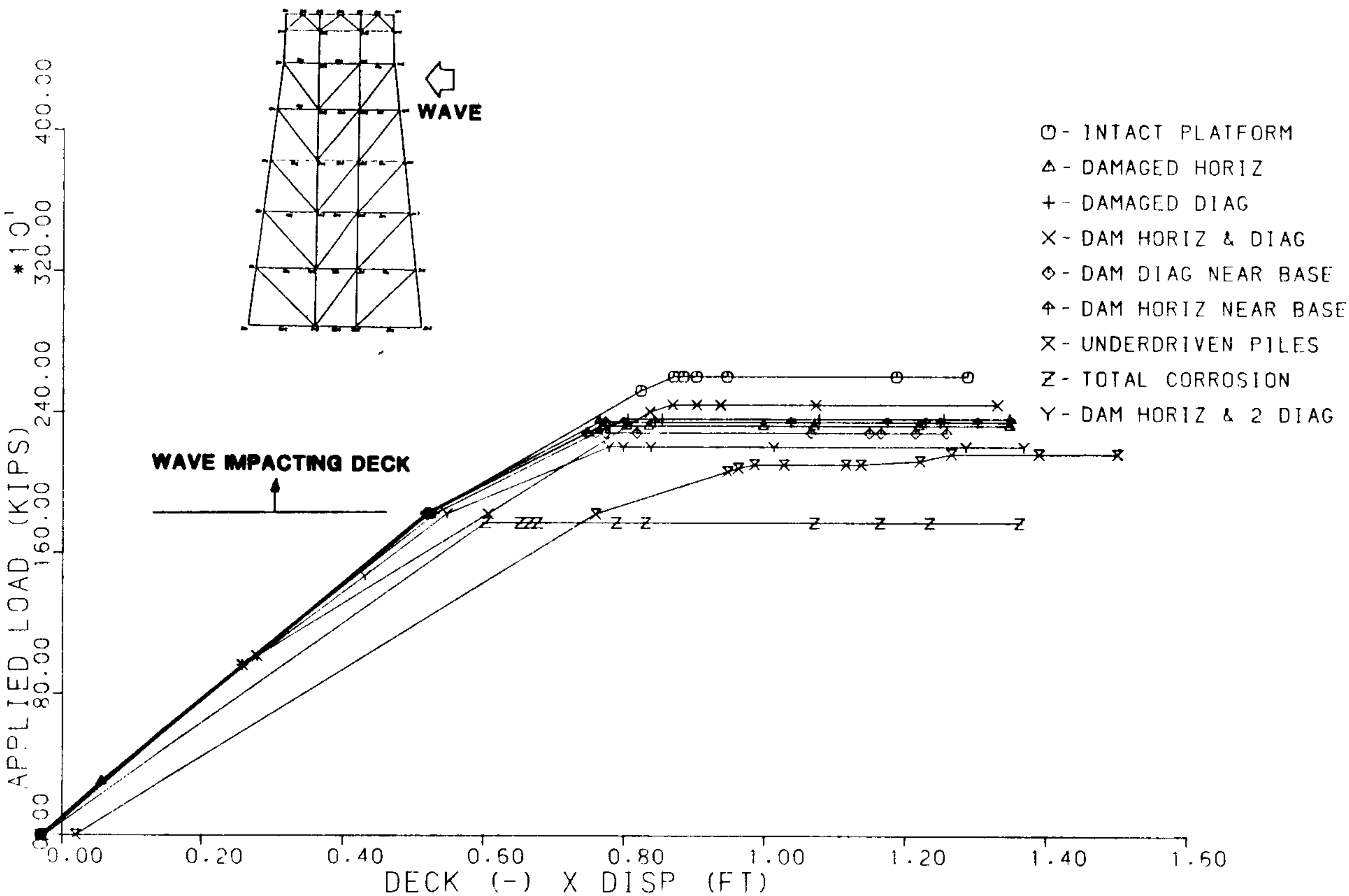
CORROSION DAMAGE



Case 1 (Y Wave)
Case 2 (X Wave)

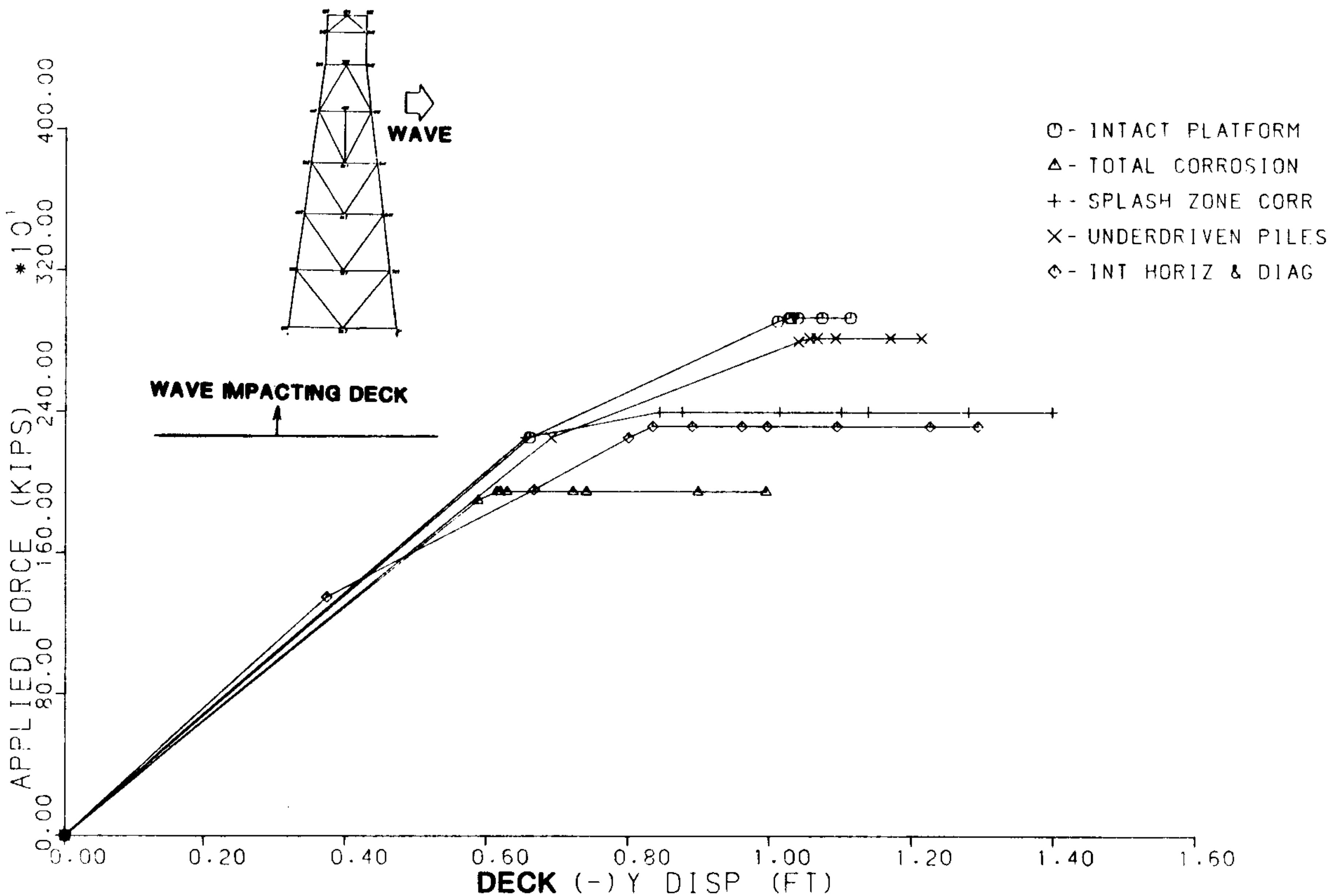
FOUNDATION DEFECTS

FIGURE 2-1 SUMMARY OF DAMAGED CASES
(Continued)



EFFECT OF DAMAGE CONDITIONS - END-ON LOADING

FIGURE 2-2



EFFECT OF DAMAGE CONDITIONS - BROADSIDE LOADING

FIGURE 2-3

3.0 CONSEQUENCES OF PLATFORM FAILURES

The information in this report is intended to provide operators with an initial starting point in estimating the potential "consequences" of a platform failure and help develop the basis for AIM decisions that will be needed in the future. Consequences are defined as the sequence of events that takes place as a result of platform failure. Examples are injuries, pollution, cleanup, salvage, abandoning of wells, and platform replacement.

This task gathered failure consequence information for the Gulf of Mexico. Other regions were at first considered; however, there was a desire to keep the data base congruent by limiting information for only one region, thereby maintaining a consistent reference area were environmental and operating conditions are generally the same.

The data base considered fixed platforms only. In addition, all of the failures are the result of storm induced damage. Fixed platforms and storms are the current thrust of AIM studies, although the AIM approach is applicable for other situations (jackups, blowouts). Multiple well and single well platforms are included. The period covered by the data base is 1948 thru 1988.

Sources of data included open literature, interviews of key personnel in the industry at the time of most of these failures (1960's), participant input, private channels (personal contacts) and existing data bases (e.g MMS). The data was collected and input to a PC data base program for easy manipulation and automatic cataloguing. The data base was provided to all participants in R:Base or dBase format for installation on their own PC's.

Table 3-1 summarizes the key information in the data base. There are a total of 38 platforms catalogued. The data is sorted according to the hurricane associated with the failure.

Table 3-2 shows a detailed summary of one of the individual platform failures. Some general information is provided about the platform, followed by detailed accounts about the failure and associated consequences.

In all of these cases there has been no known deaths or severe injuries. In terms of pollution, there have been seven known blowouts of some 140 wells, releasing approximately 10,000 to 15,000 bbls of oil to the environment. In comparison, in the year 1970 it is estimated that approximately 16 million bbls of oil were released into the oceans due to all marine operations.

Detailed cost data was difficult to obtain for the failures. However, the historical cost of clean up, salvage, replacement and/or repairs does not necessarily have a direct bearing on an AIM decision that will be needed in the future. Methods and the associated cost to salvage a platform in 1965 would be much different from today's methods and costs. The significant item is that the platform was salvaged.

The data base provides an initial starting point for estimating consequences of platform failure for a Gulf of Mexico location. Future studies may compile similar information for other offshore regions.

AIM FAILURE CONSEQUENCES DATABASE
DATA SORTED BY PLATFORM/LOCATION

PLATFORM	COMPANY	STORM	DATE	DAMAGE
E. CAMERON	SHELL	CARLA	09/01/61	SEVERE DAMAGE
EUGENE ISLAND 175-A	SINCLAIR	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 188	SHELL	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 198	PLACID	CARLA	09/01/61	SEVERE DAMAGE
EUGENE ISLAND 198-B	PLACID	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 208-A	CATC	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 208-C	CATC	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 208-D	CATC	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 276	UNION	HILDA	10/03/64	COLLAPSE
GRANDE ISLAND 1	HUMBLE	GRND ISL	09/01/48	COLLAPSE
GRANDE ISLAND 2	HUMBLE	GRND ISL	09/01/48	SEVERE DAMAGE
MAIN PASS 129	PHILLIPS	BETSY	09/09/65	COLLAPSE
S. TIMBALIER 86 PL.A	ODECO	JUAN	09/27/85	COLLAPSE
SHIP SHOAL 119-A	ODECO	CARMEN	08/07/74	COLLAPSE
SHIP SHOAL 119-F	ODECO	CARMEN	08/07/74	COLLAPSE
SHIP SHOAL 149-B	SIGNAL	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 154-B	GULF	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 154-H	GULF	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 169-A	GULF	HILDA	10/03/64	SEVERE DAMAGE
SHIP SHOAL 198-C	TENNECO	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 199-A	TENNECO	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 253	PURE	HILDA	10/03/64	COLLAPSE
SOUTH PASS 24	SHELL	BETSY	09/09/65	COLLAPSE
SOUTH PASS 61-A	GULF	CAMILLE	10/07/69	COLLAPSE
SOUTH PASS 70-A	SHELL	CAMILLE	08/17/69	SEVERE DAMAGE
SOUTH PASS 70-B	SHELL	CAMILLE	08/17/69	COLLAPSE
SOUTH PELTO 19 #11	ODECO	FREDERIC	08/01/79	COLLAPSE
SOUTH PELTO 19 #13	ODECO	FREDERIC	08/01/79	COLLAPSE
SOUTH PELTO 19 #4	ODECO	FREDERIC	08/01/79	COLLAPSE
SOUTH PELTO 19 OBM	ODECO	JUAN	10/27/85	COLLAPSE
SOUTH PELTO 19 SWP	ODECO	JUAN	10/27/85	COLLAPSE
VERMILLION 104	ZAPATA	CARLA	09/01/61	SEVERE DAMAGE
W. DELTA 117-A	GULF	BETSY	09/09/65	COLLAPSE
W. DELTA 117-B	GULF	BETSY	09/09/65	COLLAPSE
W. DELTA 118	PURE	BETSY	09/09/65	COLLAPSE
W. DELTA 69 #1	CATC	BETSY	09/09/65	COLLAPSE
W. DELTA 70 #3	CATC	BETSY	09/09/65	COLLAPSE
W. DELTA 97	FORREST	BETSY	09/09/65	COLLAPSE

LIST OF PLATFORMS IN FAILURE CONSEQUENCES DATA BASE

TABLE 3-1

--------------- AIM Failure Consequences Database ---------------
--------------- Individual Case Report ---------------

Date : 09/11/88
Time : 8:52:43

PLATFORM NAME : EUGENE ISLAND 276
COMPANY NAME : UNION

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: SELF-CONTAINED
Water Depth (ft)	: 172
Number of Piles	: 8
Number of Wells	: 12
Install\Design Date	: 07/01/64
Design Criteria	: 25-YEAR
Deck Elevation (ft)	: 31
Original Plat. Cost	: $1 MILLION
Comments	: ONLY 3 WELLS WERE INSTALLED AT THE TIME OF HILDA.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
WORLD OIL, 1964	UNION REPORTS IT WILL COST $2 MILLION TO REDRILL WELLS IF THAT IS THE DECISION.
HILDA CONF. 1964	JACKET WAS PRETTY MUCH INTACT FROM -60' DOWN TO THE SEAFLOOR. ONLY ONE OF THE THREE WELLS DRILLED SO FAR HAD BEEN COMPLETED AND IT WAS NOT LEAKING.
OGJ, 10/12/64	BREWSTER-BARTLE RIG LOST WITH PLATFORM WAS WORTH MORE THAN $1 MILLION. DRILLER WAS ON THIRD WELL WHEN STORM STRUCK.
OGJ, 11/9/64	UNION PLANS TO ABANDON THE 3 WELLS DRILLED FROM THE SUNKEN PLATFORM AND ERECT ANOTHER PLATFORM AT A NEW SITE IN THE SAME BLOCK.

DETAILED CASE HISTORY OF PLATFORM FAILURE CONSEQUENCES

TABLE 3-2

4.0 AIM EVALUATION GUIDELINES

This report addresses the development of guidelines for evaluations and justifications of suitability for service. The development has been illustrated with results from platform AIM requalification experiences. The guidelines have been based on the AIM-SS (Suitability for Service) Format. This format relates a measure of the platform capacity or strength to three categories of potential consequences.

The measure of the platform capacity or strength is the Reserve Strength Ratio, RSR. The RSR is the ratio of the Ultimate Limit State (platform rendered unserviceable) capacity of the structure, R_c, to a reference force, F_r. The platform capacity is determined from static, nonlinear, push-over analyses, as discussed in Report No. 1. The reference force is determined from current guidelines that define the minimum prudent level of loadings that a new platform should be designed to resist (e.g., 100-yr loadings).

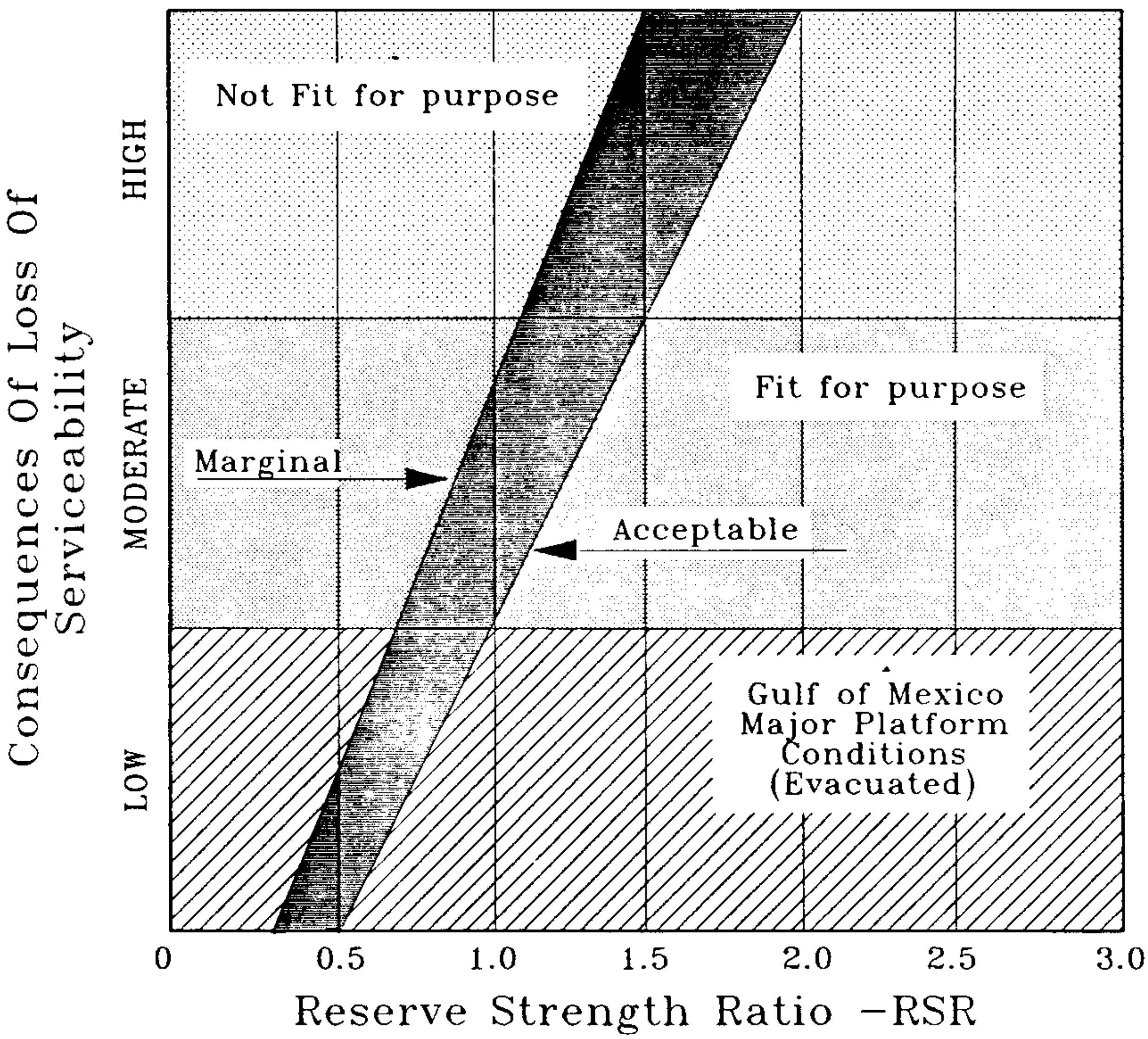
The measure of the platform potential consequences is expressed through three general categories. A Low Consequence category (Category 1) would be a platform and its AIM program that would pose no or little risks to the environment, resource, life, or property. A High Consequence category (Category 3) would be a platform and its AIM program that would pose significant or major risks to the environment, resource, life, or property. A Moderate Consequence category (Category 2) would be a platform and its AIM program that would pose hazards to the environment, resource, life, or property that are between Categories 1 and 3.

Several approaches have been developed and explored to provide quantifications for the AIM-SS analytical framework. These include historic (what has been accepted in the past), calibration (what is being accepted at the present), and utility (what represents a highest utility/lowest total cost option) approaches.

Example results from these approaches are summarized in Figure 4-1. Monetary characterizations of the consequences categories could be taken as $1 millions to $10 millions (Category 1), $10 millions to $100 millions (Category 2), and $100 millions to $1,000 millions (Category 3).

Because of their potentially unique aspects, evaluations of manned platforms have been addressed. Several approaches have been developed and explored to provide quantifications for the AIM-SS framework. These include economic, utility, and experience based valuations. Results from two high consequence platforms have been used to illustrate applications of these approaches (North Sea platform and Cook Inlet platform).

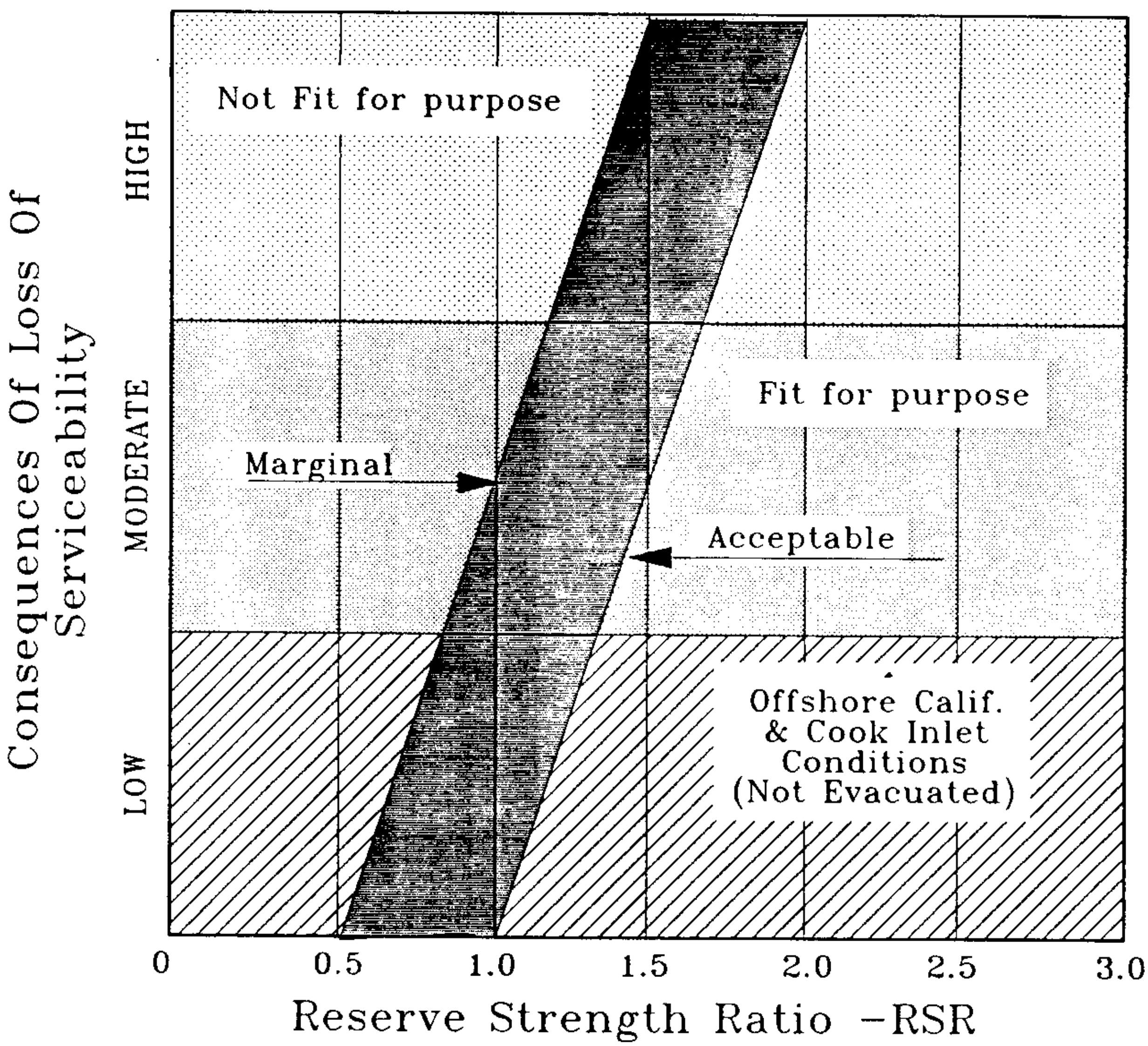
Example results from these approaches for manned platforms are summarized in Figure 4-2. The consequences scale of potential severe injuries could be related to three general categories. Category 1 could relate to 1 to 10 potential severe injuries; Category 2 could relate to 10 to 100 potential severe injuries; and Category 3 could relate more than 100 potential severe injuries.



AIM - SUITABILITY FOR SERVICE EVALUATIONS FOR GULF OF MEXICO PLATFORMS (EVACUATED IN ADVANCE OF SEVERE HURRICANES)

FIGURE 4-1

AIM 038345
PL/DISK 001
/AIM/CHRTS
FIG-A.DRW



AIM - SUITABILITY FOR SERVICE EVALUATIONS FOR HIGH CONSEQUENCE (NOT EVACUATED) PLATFORMS

FIGURE 4-2

AIM 038045
PL/DISK 001
/AIM/CHRTS
FIG-b.DRW

PLATFORM "C"

INTACT AND DAMAGE CONDITION ASSESSMENTS

AIM III

FINAL REPORT NUMBER 1

BY

PMB SYSTEMS ENGINEERING INC.

SAN FRANCISCO, CA

SEPTEMBER 1988

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1.0 INTRODUCTION

1.1 Objectives

This report describes the activities and results of the AIM III project, Tasks 1 and 2 related to assessing the intact and damaged condition performance of a medium water depth, drilling and production platform located in the Gulf of Mexico. The platform's general configuration is shown in Figure 1-1. This platform configuration was chosen because it represents a large number of platforms currently existing in the Gulf of Mexico. Many of these platforms are approaching the age where AIM type evaluation programs may be required.

The key objectives of this study were to demonstrate the reserve strength characteristics of this platform in terms of its ultimate limit state (ULS) performance. The ULS is the maximum resistance capacity of the platform against operating and environmental loadings.

The ULS capacity of the platform was determined for the "intact" state and for a series of selected "damaged" states. The intact state considers the platform in its original as-designed condition. The damaged cases were selected to represent typically observed conditions such as dented members and corrosion.

The comparison of platform performance between the intact and damaged state provides some an initial estimate of the effects on platform capacity of different types of damage. It is hoped these results will benefit participants in evaluating the potential performance of their own platforms should similar damage occur.

The results of these analysis are also used in AIM Final Report Number 3 [1] dealing with Evaluation Procedures of the AIM Process.

1.2 Background

The AIM I Project [2] developed a general engineering approach for requalifying existing offshore platforms. The approach requires an estimate of the platform's performance in terms of ability to resist imposed loadings. This performance assessment was demonstrated in the AIM II Project [3] for two, early generation, shallow water (50 ft and 140 ft) platforms (Platform "A" and Platform "B") located in the Gulf of Mexico.

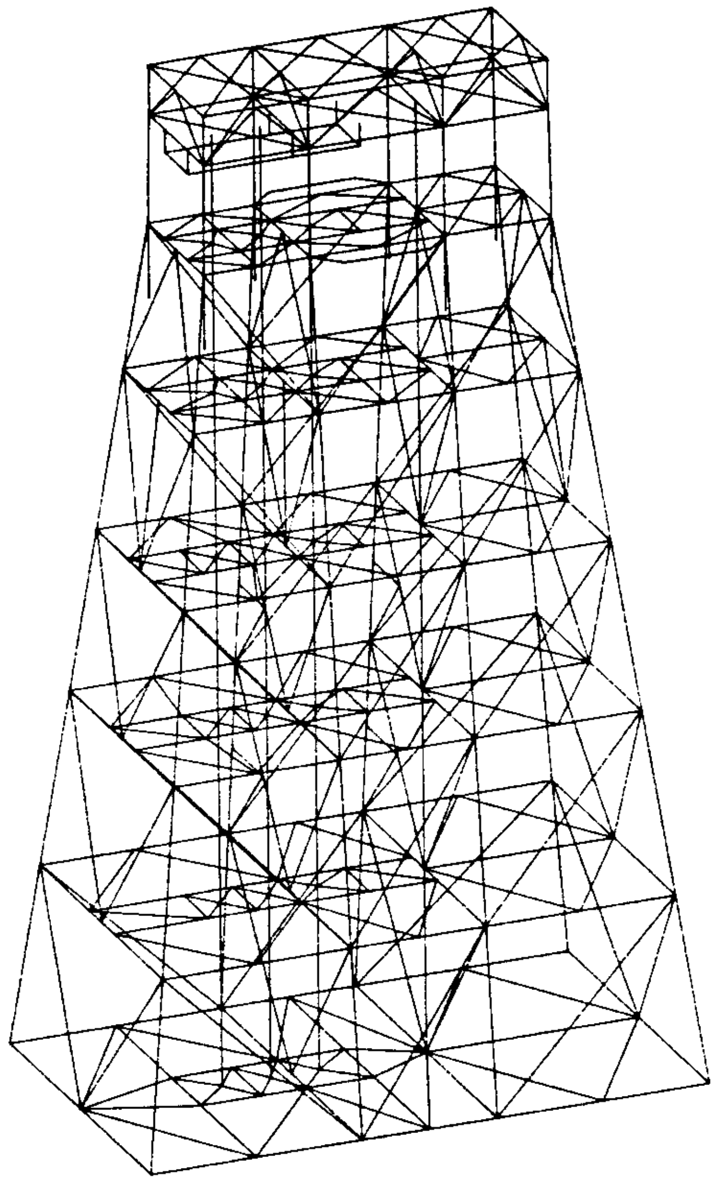
The performance of these platforms was determined in both an intact (as designed) and damaged (as-is) condition. The results of the assessment were used in the AIM evaluation process to determine potential repair and requalification programs for the example platforms.

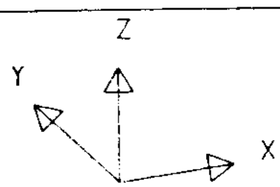
The performance assessment used a sophisticated, nonlinear computer program [4] to determine the platform's maximum load carrying capacity achieved at the platform's Ultimate Limit State (ULS). This analysis provides the platform's capacity at its collapse load. To generate the ULS capacity, the computer program applies loading to the platform, and mimics the buckling and yielding of platform members until the remaining platform elements can no longer resist environmental or topside loadings.

Following completion of AIM II, several participants noted that there was a need to make a similar evaluation of a more typical platform than platforms "A" and "B" that was of a later generation with a more complex geometry. To achieve this goal, the AIM II project was divided into several tasks, with each making a detailed investigation into a key area of the AIM process - platform performance, consequences of platform failure, and evaluation procedures.

This report describes the findings of the platform performance assessment for the subject platform. The platform was identified as Platform "C" to carry on with the terminology of the AIM II project which studied platforms "A" and "B."

PMB Systems Engineering Inc, San Francisco, Calif. 94111





GLOBAL AXES

PLATFORM "C" CONFIGURATION

FIGURE 1-1

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2.0 SCOPE OF WORK

2.1 Platform Evaluations

This task of the AIM II project is primarily involved with platform strength evaluations. As previously noted, Platform "C" will be the subject platform for the strength assessments. The key issue is to determine the effect on platform performance, measured in terms of capacity, due to different damage conditions (Figure 2-1).

The platform's geometry and strength conditions will be used to develop a computer model for use in simulating platform loading conditions and determining the platform's capacity. The program uses sophisticated modeling techniques to properly reflect the strength behavior of the platform's components.

The following methods are used for simulating the key components:

Foundation: Soil-Pile interaction is accounted for with explicit nonlinear elements located along the pile's length.

Braces: Strut elements that mimic the response of these slender members (high kl/r) in compression by buckling and in tension by yielding.

Legs, Piles: Nonlinear beam elements that mimic the response of these members (low kl/r) in bending, compression, tension and torsion by yielding.

The use of these special modeling techniques is required to determine the ultimate capacity of the platform. The nonlinear members are required to properly reflect changes in platform response when members "fail" as the platform reaches capacity. If the more typical linear members were used, as in standard design approaches, the estimated platform capacity would be in error since members that had failed would no longer be contributing their proper proportion to the platform's capacity.

Once the platform model is developed, an estimate of the environmental conditions at the site is made. Oceanographic conditions includes waves, wind, current and tide. Soil conditions are estimated and used to develop the foundation computer model. The environmental conditions are used to develop force profiles that are subsequently used to determine the platform's capacity.

Using the computer model and the environmental force profile, the platform's capacity is then determined for the intact condition. The intact condition results provide a base case estimate of the platform's capacity.

Additional sets of analyses were run for a series of damage cases. These damage cases include dented and bent members, missing members, corrosion and defective piles. The results of these damage cases provides a first level estimate of the effect on platform capacity of different kinds of damage.

Some work scope was also set aside to investigate a more refined method for determining wave forces on deck components (girders, equipment). This was originally defined as one of the damage cases, but is instead reported in an independent section due too the unique nature of this case.

2.2 Work Products

Work products of this task include:

- Platform "C" geometry and member description
- Site geotechnical conditions
- Site environmental conditions
- Computer model description
- Analysis procedures
- Platform environmental forces
- Intact condition assessments with discussion
- Damage condition assessments with discussion
- Refined procedure for computing wave loads on decks
- Observations and Conclusions

All of these work products are included within this final report for this task.

3.0 PLATFORM "C" CONFIGURATION

3.1 Platform Description

The platform is located in the Main Pass area of the Gulf of Mexico located offshore from Louisiana (Figure 3-1). Water depth at the site is approximately 271 feet. The region is prone to high winds and large waves developed by hurricanes passing through the Gulf of Mexico.

The platform is a self-contained drilling platform designed in 1968-1969 and installed in 1970. There are 24 oil producing wells on the platform. The platform is continually manned, but evacuated in advance of hurricanes. Table 3-1 summarizes the key characteristics of the platform.

Figures 3-2 through 3-4 show typical elevations and plan views of the platform detailing geometry and member sizes. The jacket is an eight leg template type with a typical leg diameter of 44 3/4 inches and 1/2 to 5/8-inch wall thickness. Major exterior diagonal and horizontal brace sizes range from 14 to 30 inches with 3/8 to 1/2-inch wall thickness. Internal horizontal members range in size from 8 5/8 to 18 inches with a similar range of wall thickness.

The eight 42-inch piles (Figure 3-5) penetrate to a depth of 270 ft into medium sands overlying stiff clays. Pile wall thickness ranges from 7/8 to 1 5/8 inches. The piles extend through the jacket to an elevation of +15 feet where they extend through the top of the jacket leg to provide a connection point for the deck legs. The piles are grouted to the jacket leg.

The deck uses a truss type tubular support system (Figure 3-6) to distribute loadings. The lower deck is located at about elevation +46 ft and the upper deck is located at about elevation +63 feet. There is an interior sump deck located at about elevation +35 feet. The deck legs transition from 42 inches at +15 feet to 36 inches at +29 feet and extend with this size up to the upper deck level. The deck weighs about 600 tons. The topsides equipment is assumed to weigh 5500 tons and is evenly distributed to each leg.

There are two boat landings of typical Gulf of Mexico design located along Rows A and B of the platform. Barge bumpers are used around the platform to protect exposed platform legs. The main type of corrosion protection is sacrificial anodes.

3.2 Geotechnical Conditions

Figure 3-7 shows the soil conditions at the site [5] as a function of depth below mudline. The information is based upon a boring taken near the platform's site. The soils consist of fine to medium sands between the mudline and -245 feet with stiff clays below this level. Figure 3-8 shows the interpretation of the boring information to be used to establish foundation conditions for the site. The sand friction angles range between 25 and 30 degrees. The stiff clay has a shear strength of about 2000 psf at -250 feet, increasing with depth beyond this point.

3.3 Oceanographic Conditions

Oceanographic conditions at the site consist of waves, currents, winds and tides. The characteristics for these items are discussed using current platform design criteria (1988) and the original design criteria (1969). The 1988 design criteria utilizes API RP2A [6] recommendations complemented with some site specific studies [7,8]. The 1969 design criteria utilizes the condition typically used by the industry at that time [8,9,10]. The intent is to compare the two types of criteria to determine how they influence platform loading.

The 1988 return period wave heights for the site are shown in Figure 3-9. The 100 year return interval wave is 70 feet which is about the same as the API RP2A reference level wave height for this water depth. The wave height increases with return period until a value of about 100 feet which is the maximum credible wave height for Gulf of Mexico conditions. Also shown on Figure 3-9 is the 1969 wave height of 58 feet for this site.

The 1988 storm surge and wind speed conditions for the site are shown in Figures 3-10 and 3-11, respectively. The 1969 storm surge is also shown on Figure 3-10. The 1969 wind conditions were taken as the same as the 1988 conditions.

Wave crest elevations were computed using a 9th order Stream function, which for this water depth provides similar results as would be computed with a 5th order Stokes theory. Figure 3-12 shows wave crest elevation as a function of return period for the 1988 design criteria. Also shown is the 100 yr 1969 crest elevation. The crest elevations for the 1988 criteria were developed using a 1/12 wave height to wave length ratio (e.g. 12.8 secs for the 100-year wave). The 100-year 1969 crest elevation is computed using a 16-second wave period.

The 1988 wave crest elevations indicate that waves with return periods greater than 100 years will impact the major deck sections. The lower 1969 waves indicate about a 7-foot gap between the wave crest and the lower deck for the 100 year wave. Based upon this data, the platform, which was designed with the 1969 criteria, has its lower deck set at too low an elevation according to today's design standards. Today's standards call for a 5-foot air gap between the crest of the 100-yr wave and the lowermost deck element [6].

Marine growth at the site is taken as 1 inch added to the member's radius for all members located between the waterline and -100 ft.

3.4 Environmental Forces

Environmental forces acting on the platform were computed using a three-dimensional platform computer model and a two-dimensional wave grid. This process computes forces along a member's length and then distributes them back to the member end (node) for each increment of the wave moving past the platform. The loading on each member throughout the platform is then summed to determine the platform's base shear. The loads at each member end are saved for possible later use in developing a load profile to use in determining the platform's capacity.

This process is repeated as the wave is moved through the structure. For this study, each wave was moved through the structure in 24 increments in order to compute the maximum base shear. Wave forces were determined for the end-on X direction and the broadside Y direction.

The computation of the wave loads acting on a member uses the standard Morison equation [6]. For the 1988 conditions, the C_d was taken as 0.7 and the C_m as 1.5 [3]. An additional case was run for the 100-yr wave for a condition of $C_d = 0.6$ to conform with API RP2A recommendations. The 1969 criteria specifies a C_d in the range of 0.6 to 0.7 and a C_m in the range of 1.4 to 6.0, depending upon the member's diameter.

Based on this selection of drag coefficients, the current was not explicitly included in the 1988 force computations (i.e. current velocity not added to wave particle velocity [6,36]). Thus, the current was assumed to be implicitly included in the force estimation in terms of the C_D and is offset by other factors not explicitly accounted for by the analysis (e.g., directional spreading). However, the 1969 design criteria [8,9,10] explicitly defines the inclusion of currents into the environmental force formulation.

Table 1-2 provides a direct comparison between the 1988 and the 1969 conditions for determining environmental forces.

Wind forces were computed using the standard API RP2A formulation assuming a drag coefficient of 1.0 for clear decks, 1.5 for cluttered, but not blocked decks, and 2.0 for blocked (no visible light thru deck) decks [3]. The sump and lower decks were assumed to be "cluttered" while the upper deck was assumed to be "clear" with equipment stacked (on average) 5 feet. This resulted in a wind loading of about 80 kips in the end-on X direction and 160 kips in the broadside Y direction for a 100-year return period condition.

Figure 3-13 shows the resulting maximum wave plus wind loads acting on the platform as a function of return period. The broadside Y-direction loads are larger than the end-on X-direction loads due to the wave front impacting more members at the same time, particularly the conductor groups, when traveling perpendicular to the broadside direction.

The wave begins to impact the deck at the 100-year return period condition. Platform loadings beyond this return period are shown with two plots. The "force w/o deck" plot assumes no deck is present but the platform's legs continue upward. This would be the resultant wave loading if the deck were positioned at a higher elevation.

The "force w/deck" plot assumes waves are impact the deck support elements and the topsides equipment. The additional loading due to this condition was computed by hand calculations and then added to the "force w/o deck" plot to determine the total load on the platform. The wave impact loads were computed using full impact area for a particular wave and a C_d of 2.0. This C_d was modified according to guidelines recommended by DnV [11] that reduce the C_d according to aspect ratio of impacted area. The resultant C_d was in the range of 1.3 to 1.6. Wind forces were added to the deck loading by considering the remaining exposed deck area not covered by the wave.

As an example, the wave plus wind loading on the deck for a 200-yr wave, which is about 5 feet into the lower deck, is about 340 kips (acting on deck) in the end-on X-direction and 640 kips (acting on the deck) in the broadside Y-direction. About 20% of this loading is due to winds. The wind forces are negligible for larger waves, which cover a greater portion of the deck area and apply considerably higher loadings. Section 7.0 outlines more advanced techniques for determining forces on decks due to wave impact.

Also shown on Figure 3-13 are the 1969 wave forces for a 100-yr wave. These forces are higher than for the 1988 criteria. This is caused by the inclusion of currents in the 1969 force formulation. However, the center of load distribution for the 1988 criteria will be located higher on the structure due to the higher design wave height (70 feet versus 58 feet). This causes a greater overturning moment on the platform and likely reduces its ultimate capacity.

The last information shown in Figure 3-13 are the wave forces for a 100-yr return period wave considering a C_d of 0.6. This is the recommended C_d in API RP2A and provides a base case condition for a "reference" level loading force later used in RSR (Reserve Strength Ratio) estimations.

- Gulf of Mexico
- Main Pass Area - 271 ft. W.D.
- 8-Leg Template
- 24 Wells
- Self-Contained Drilling Platform
- Designed 1968-1969, Installed 1970
- Oil Producing
- Manned (Evacuated in Advance of Hurricanes)
- Eight 42-inch Piles
- Maximum Penetration 270 Feet
- Sands Overlying Stiff Clays
- Designed with 1969 Wave Criteria
- Lower Deck at +45 Ft
- Sump Deck at +35'-6"
- Deck Weight = 600 Tons
- Topsides Weight = 5500 Tons
- Risers 1 at 16" Diameter
2 at 10" Diameter
- Pump Casings 3 at 16" Diameter
- Two Boat Landings
- Barge Bumpers
- Sacrificial Anodes Corrosion Protection

PLATFORM "C" KEY DATA

TABLE 3-1

100 YEAR DESIGN CONDITION

1988 CURRENT DESIGN

VS.

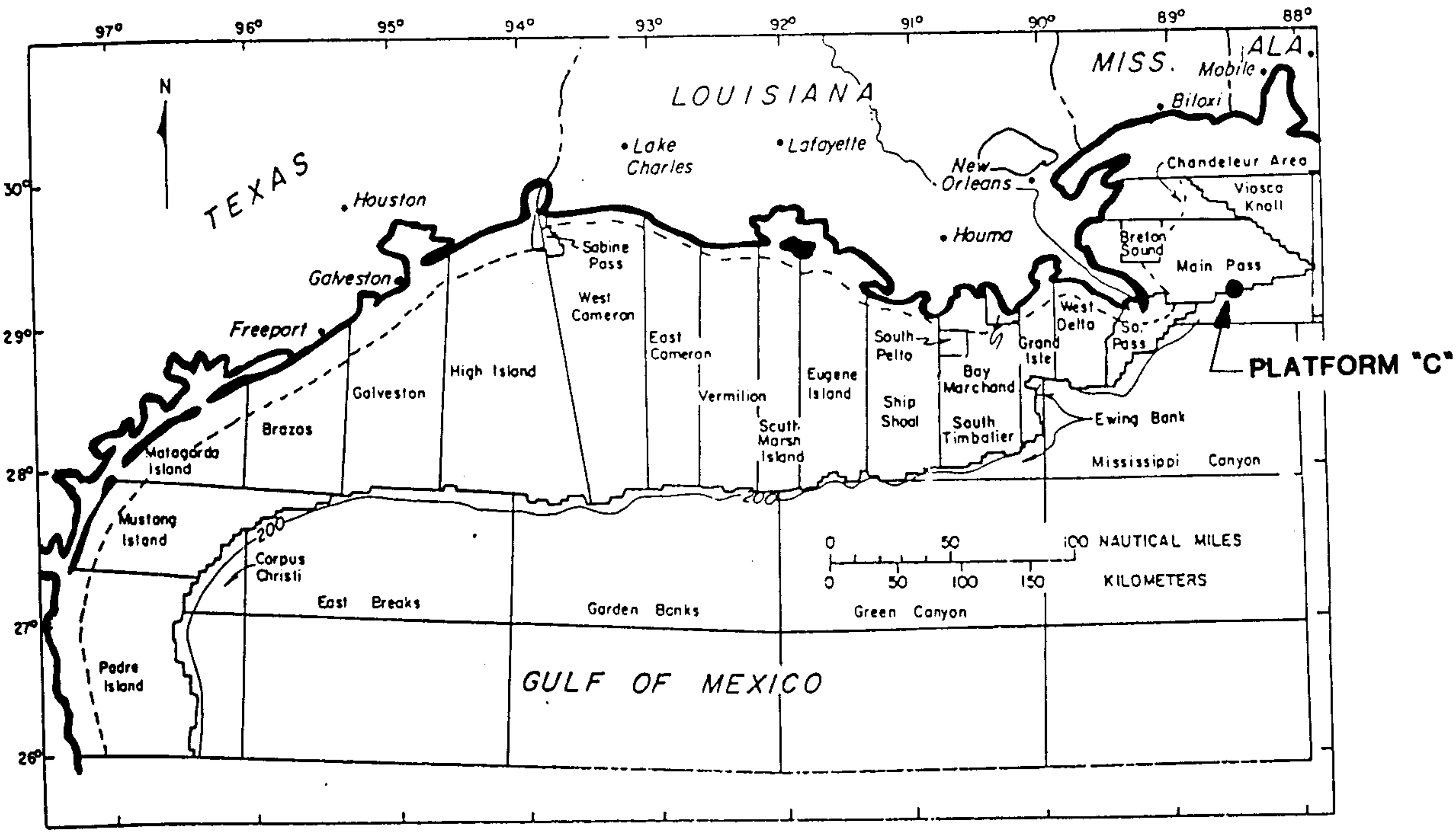
1969 ORIGINAL DESIGN

Item	Current 1988	Original 1969
H100 (ft)	69	58
T (sec)	12.8	16
Current (fps)	None	MWL 3.4 fps Mud 0.4 fps
Tide + Surge (ft)	3.5′	5.7′
C_D	0.7	0.6 - 0.7(1)
C_M	1.5	1.4 - 6.0(1)
Marine Growth	1" on Radius	1" on Radius
Wave Theory	Stokes V	Stokes V

(1) Function Member Diameter

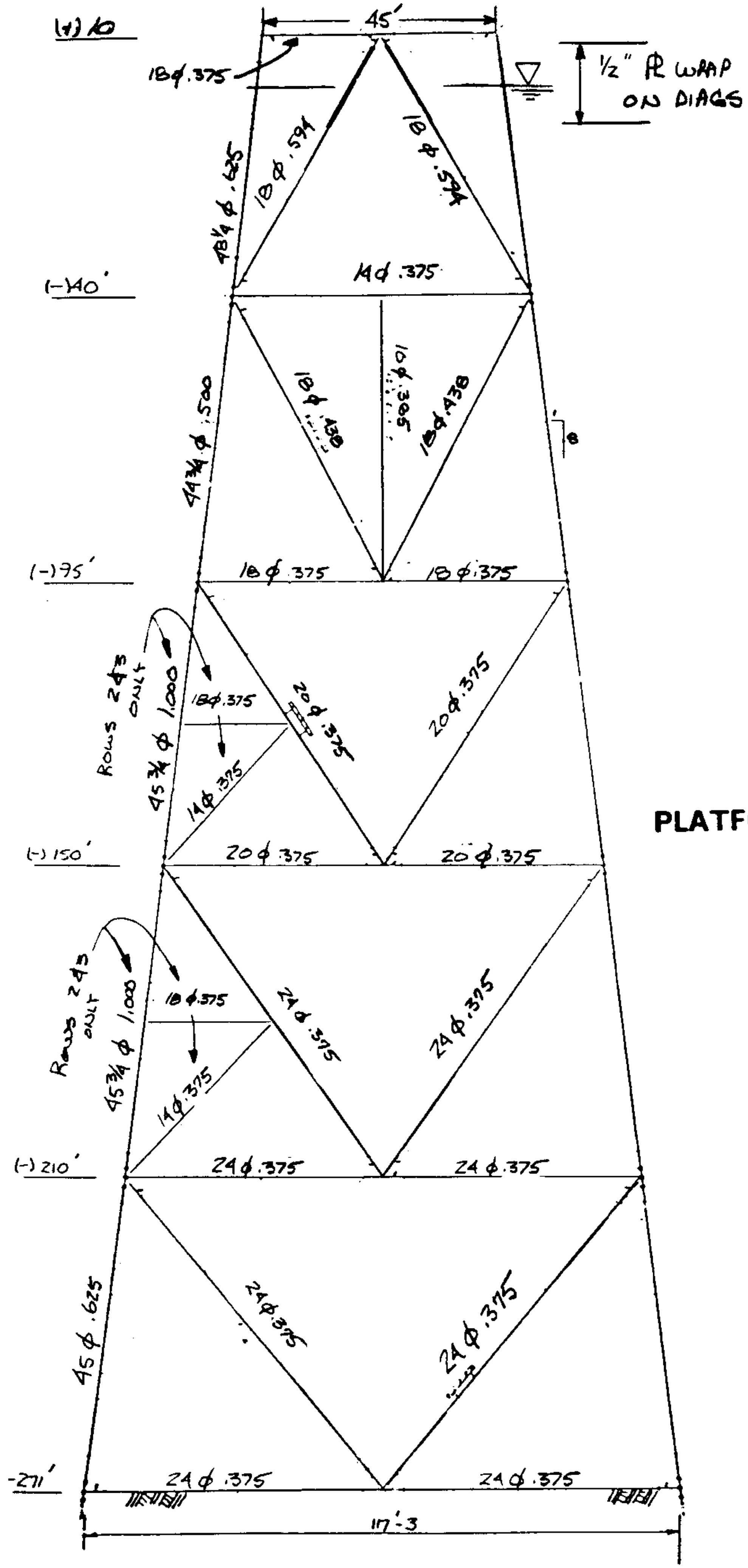
COMPARISON BETWEEN 1988 AND 1969 CONDITIONS
FOR ENVIRONMENTAL FORCE COMPUTATIONS

TABLE 3-2



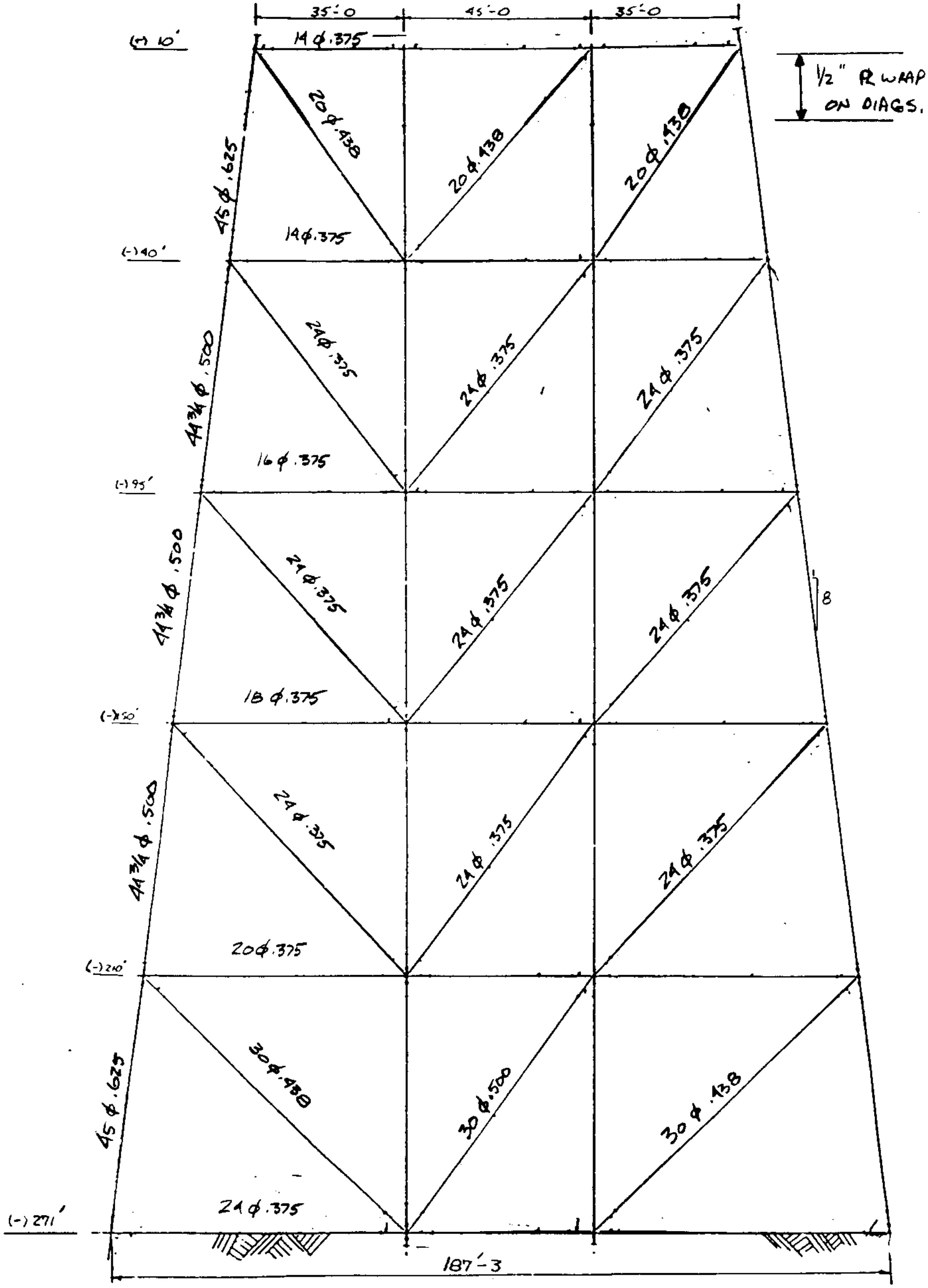
PLATFORM "C" LOCATION

FIGURE 3-1



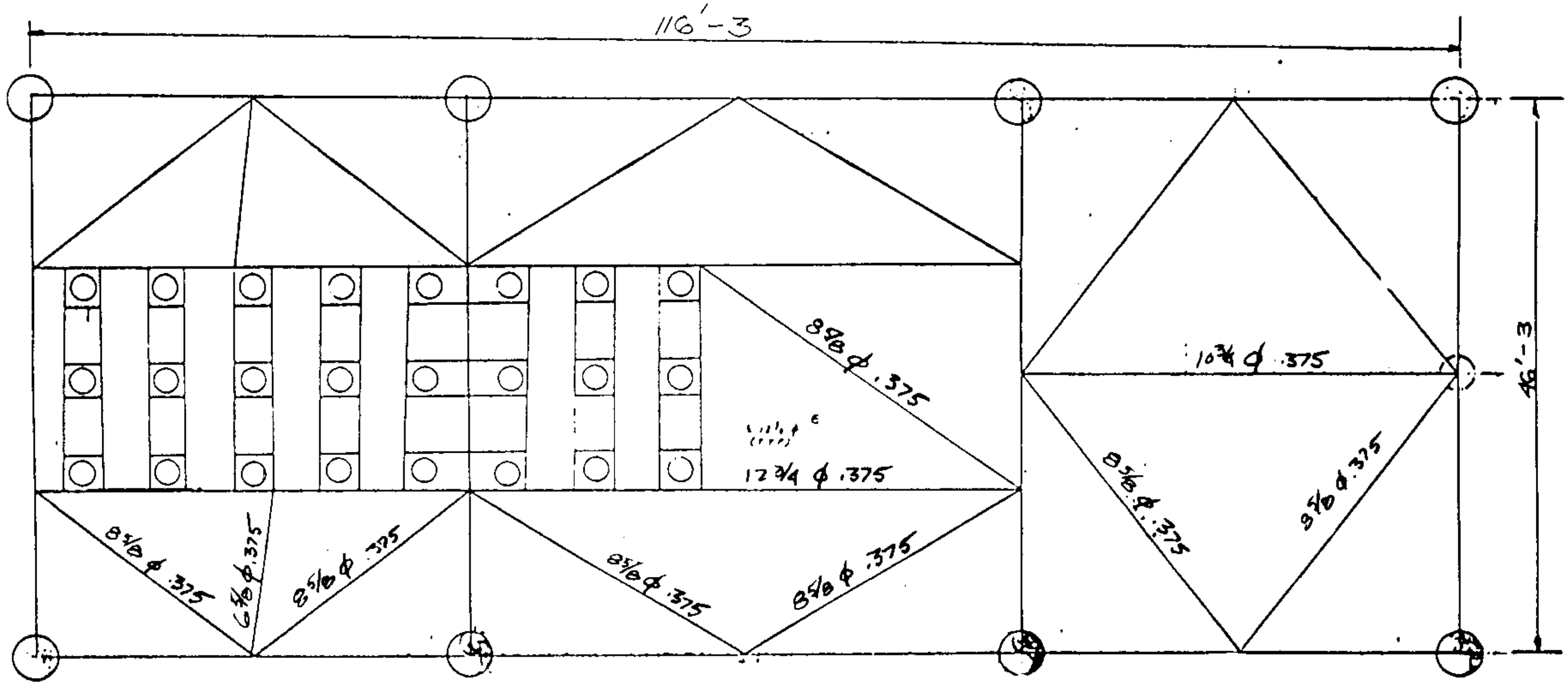
PLATFORM "C" ROWS 1 - 4

FIGURE 3-2



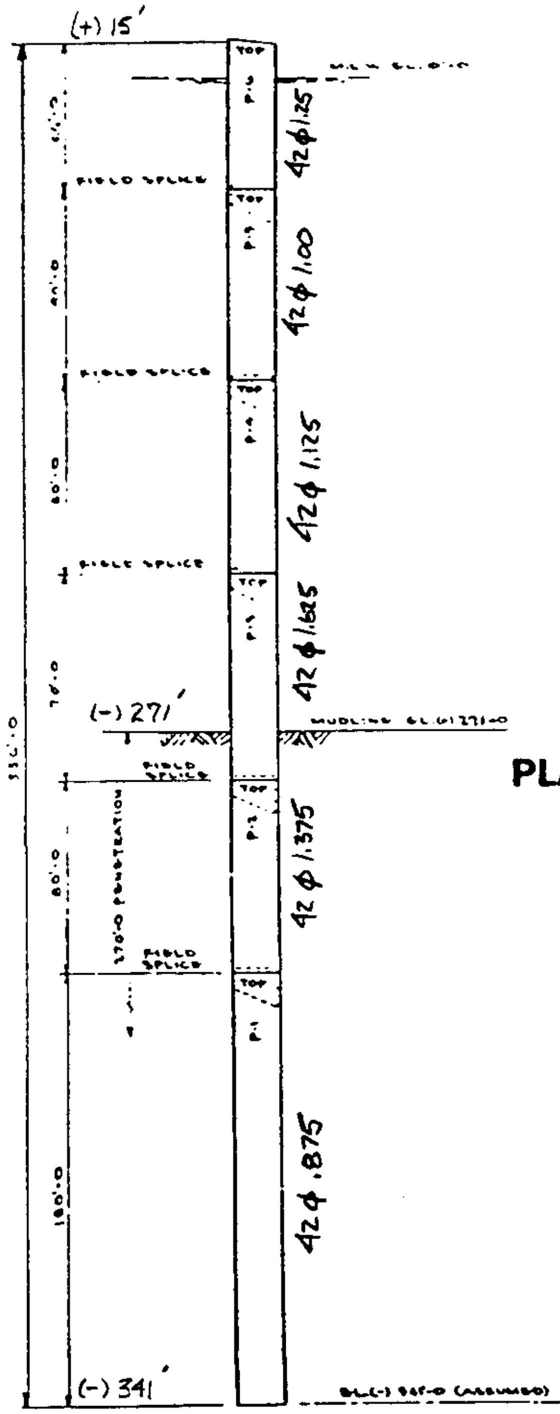
PLATFORM "C" ROWS A - B

FIGURE 3-3



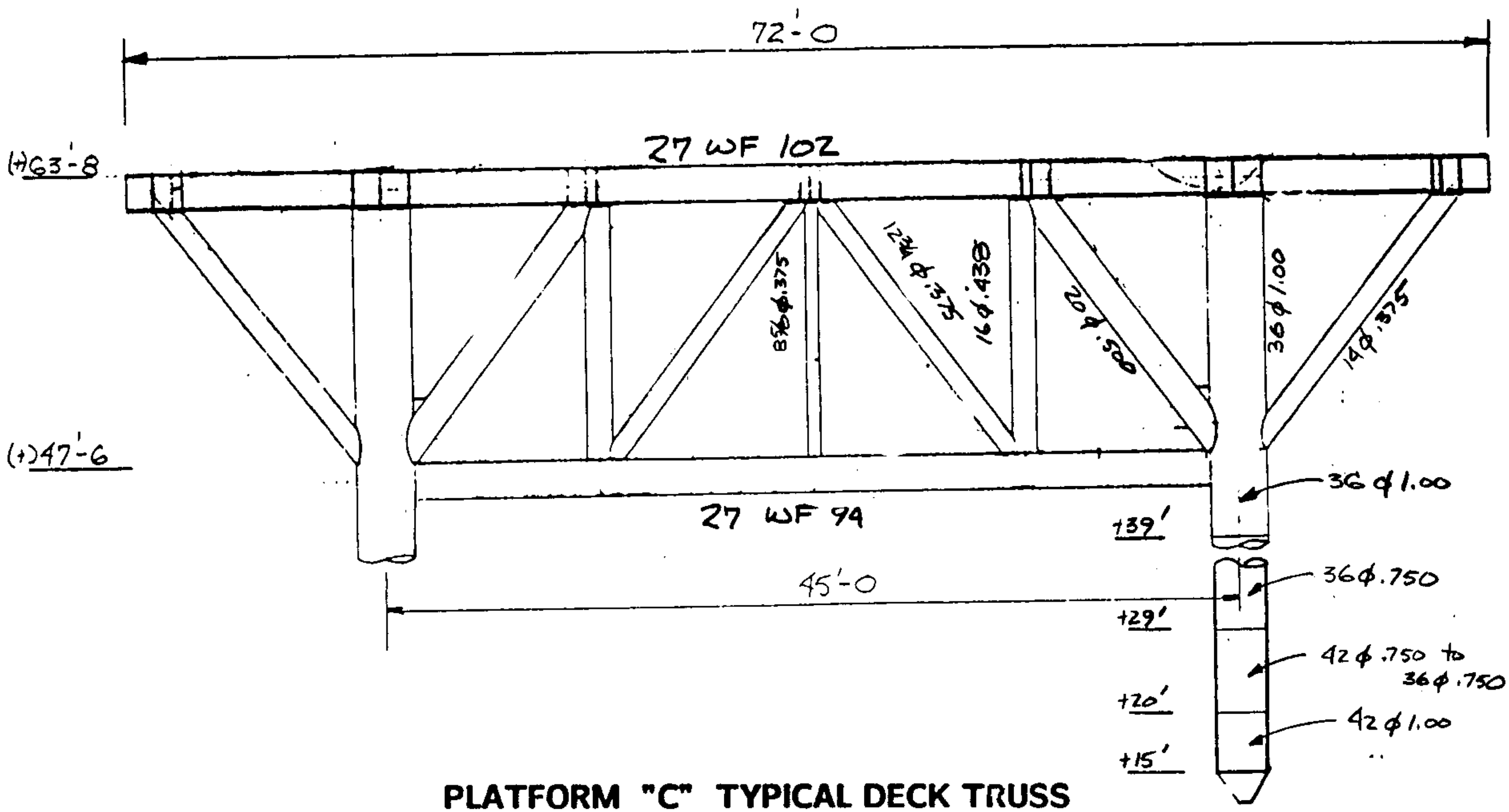
PLATFORM "C" TYPICAL PLAN VIEWS

FIGURE 3-4



PLATFORM "C" PILE CONFIGURATION

FIGURE 3-5



PLATFORM "C" TYPICAL DECK TRUSS

FIGURE 3-6

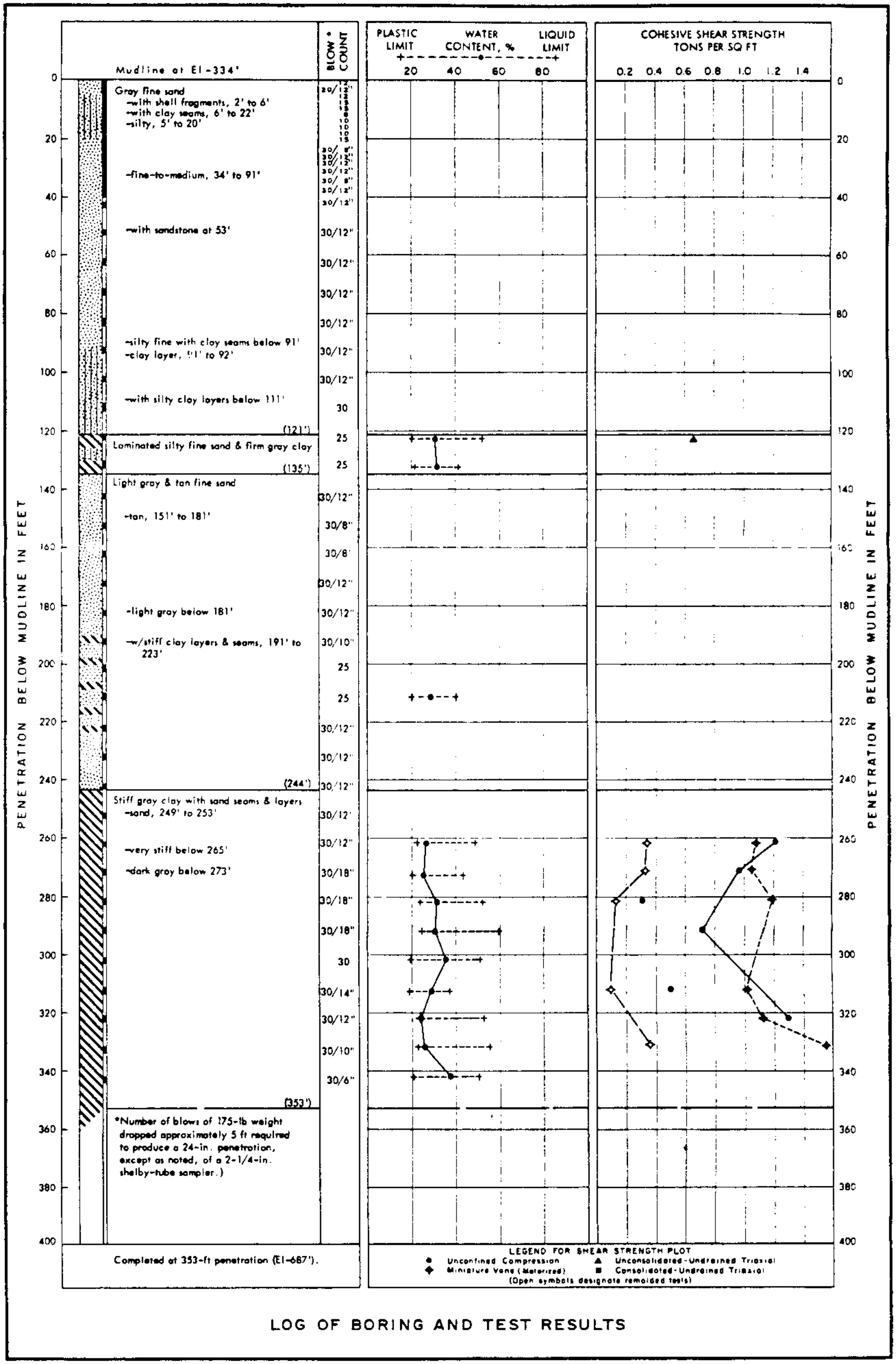


FIGURE 3-7 SOIL CONDITIONS

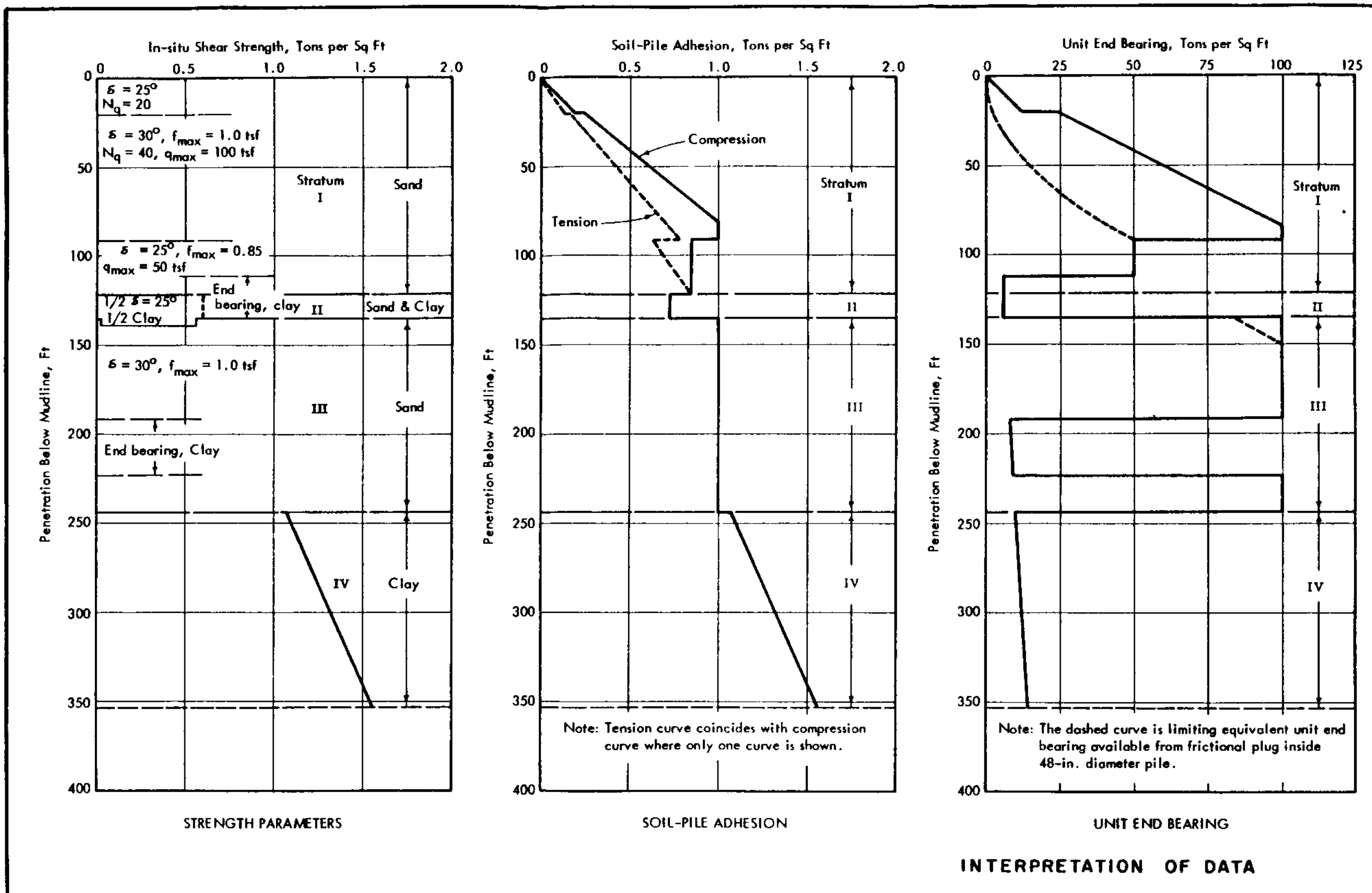
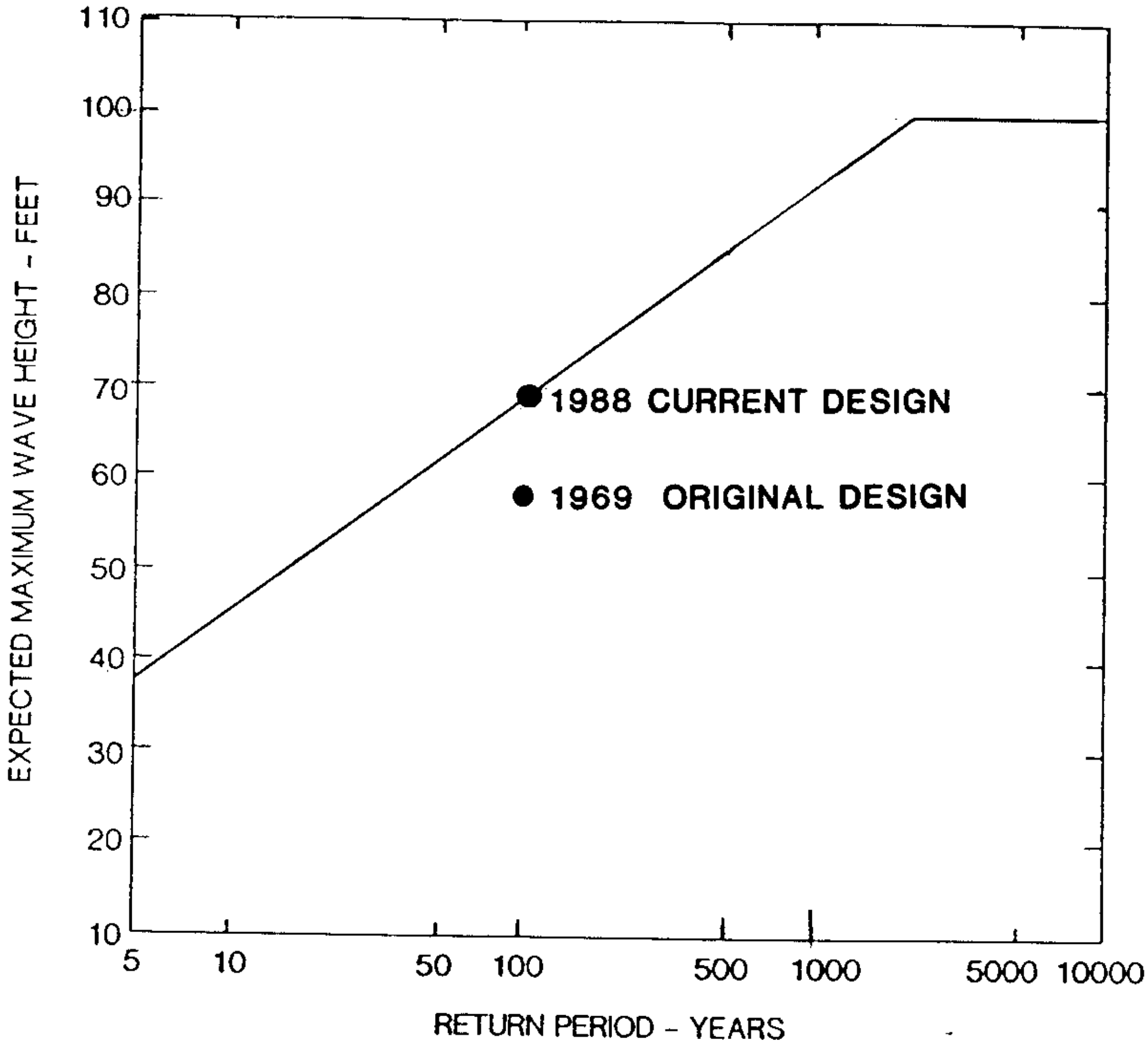
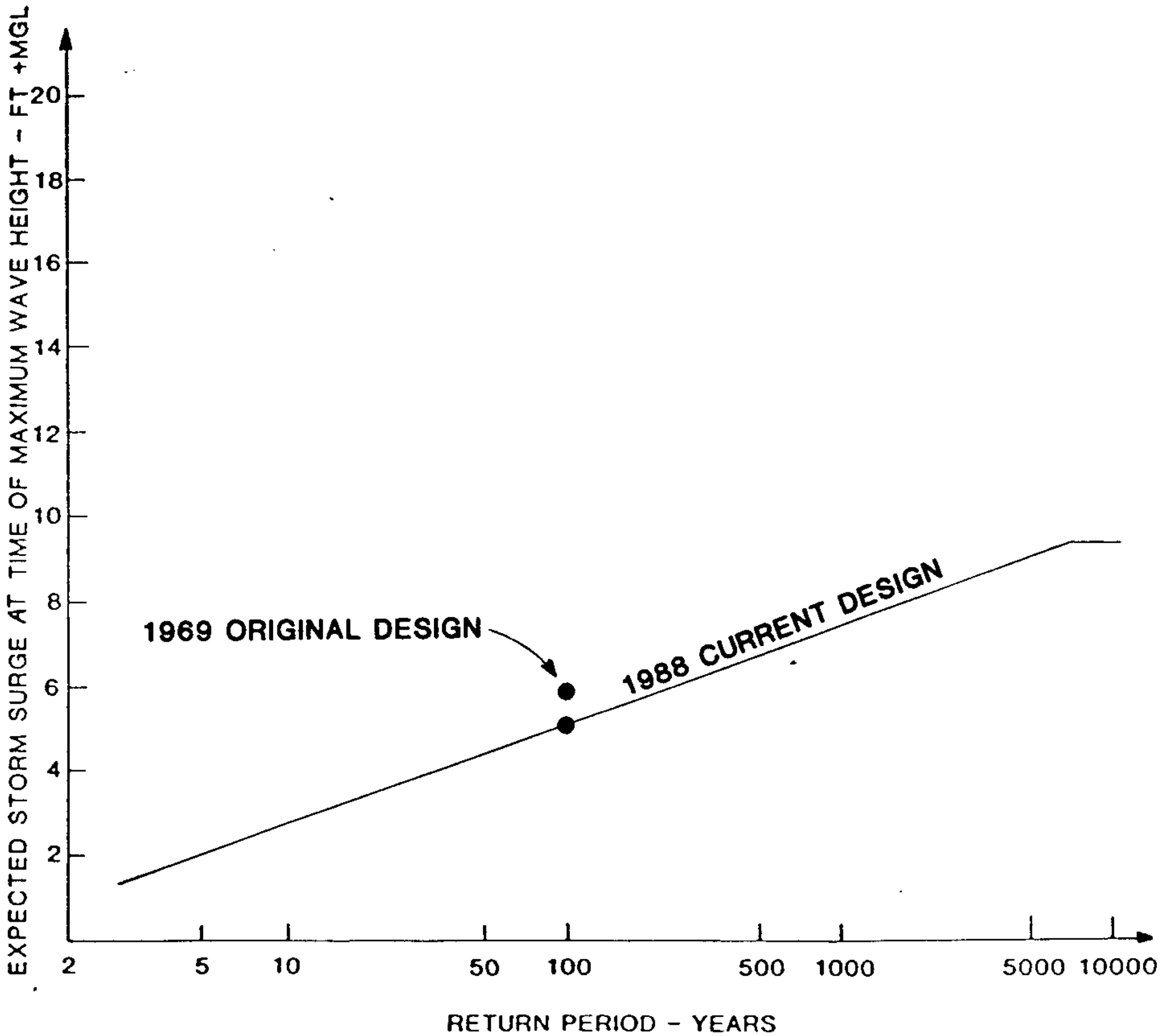


FIGURE 3-8 INTER⸺TED SOIL DATA



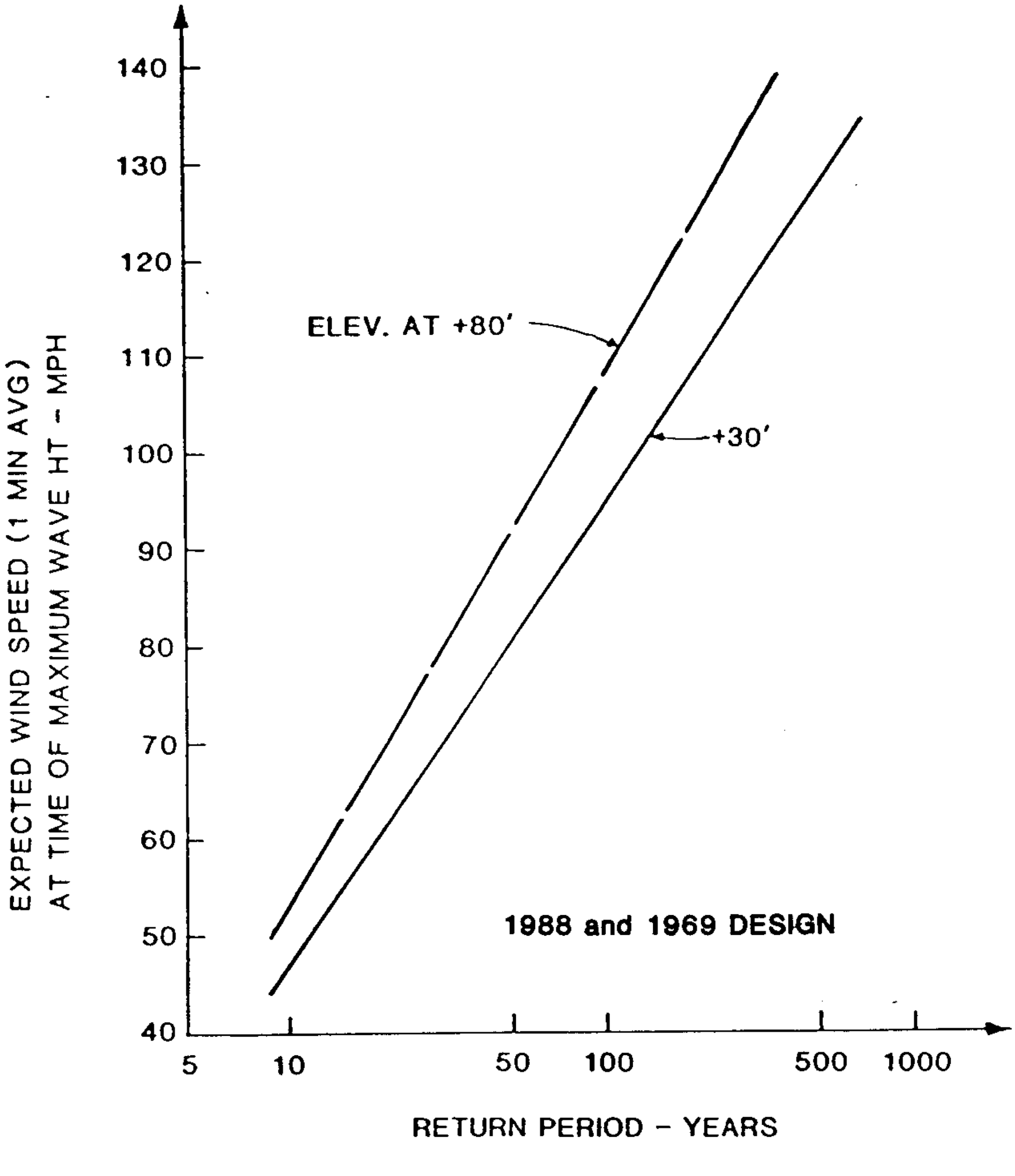
WAVE HEIGHT DATA

FIGURE 3-9



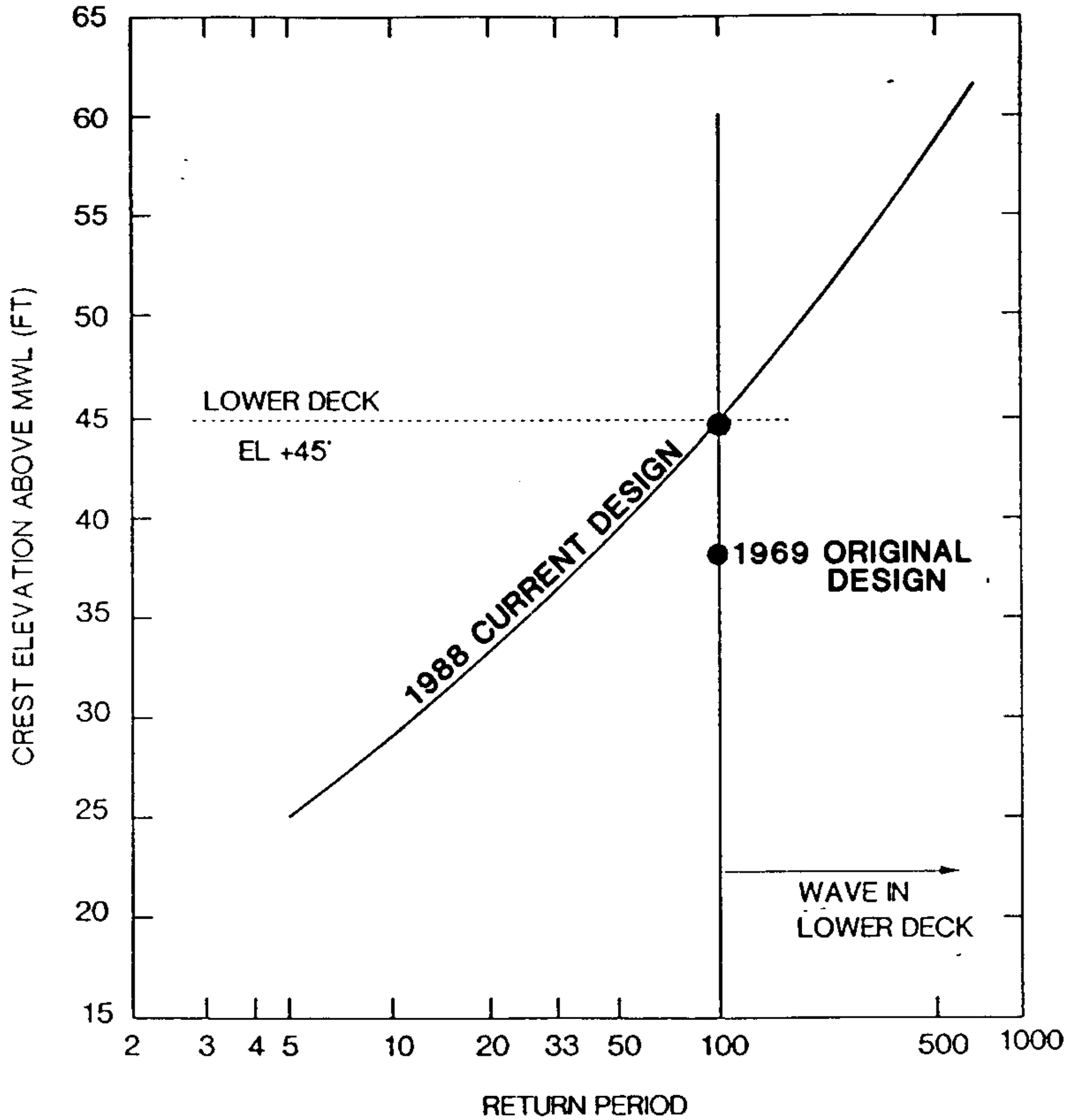
STORM SURGE DATA

FIGURE 3-10



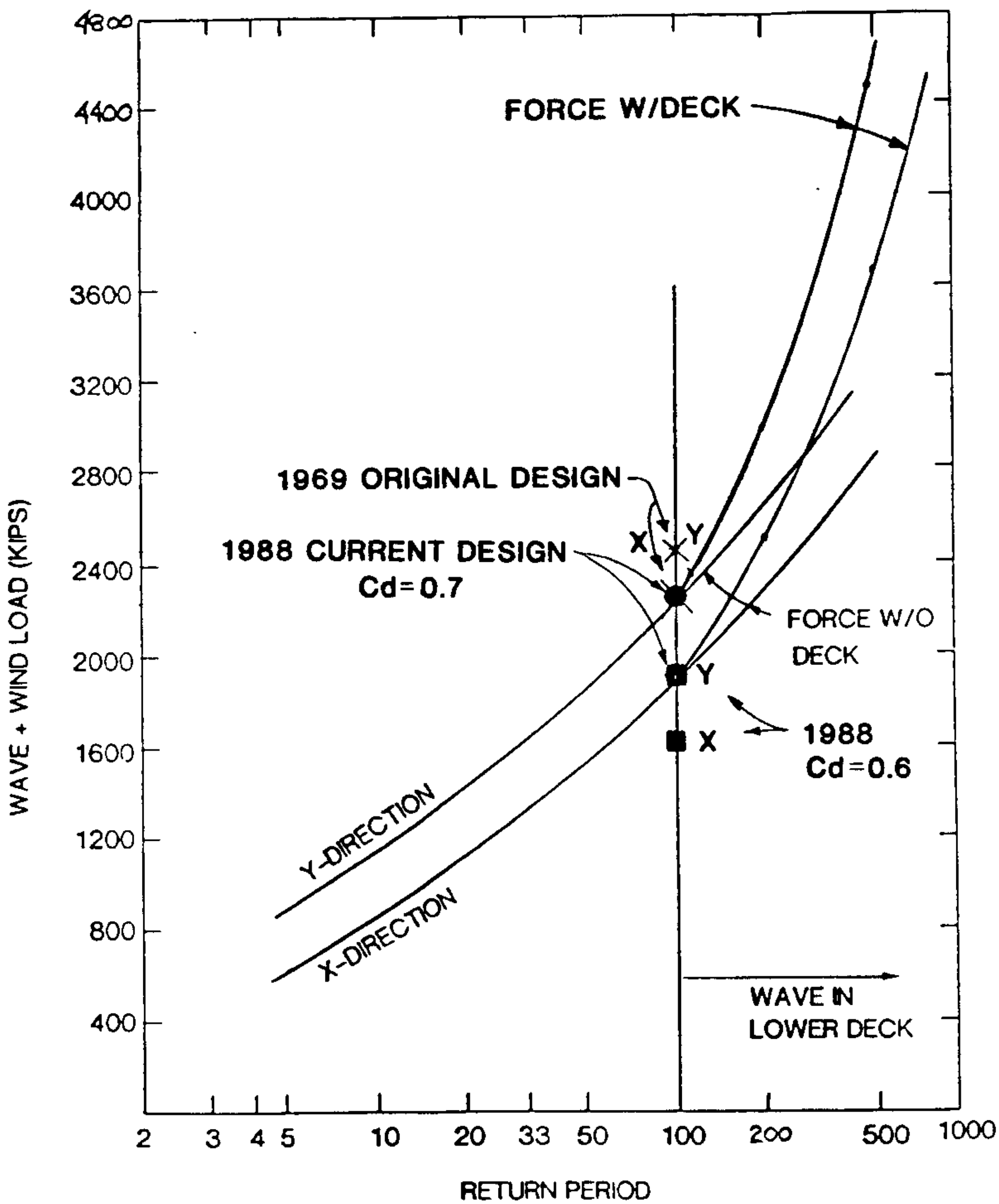
WIND SPEED DATA

FIGURE 3-11



WAVE CREST ELEVATIONS

FIGURE 3-12



WAVE PLUS WIND LOADING

FIGURE 3-13

4.0 ANALYSIS PROCEDURES

4.1 Ultimate Limit State Analysis

The Ultimate Limit State (ULS) analysis determines the maximum resistance available in a structure to act against loadings. This is an unfactored resistance excluding any inherent safety factors and counting on all elements of the platform's structural system (e.g. launch truss framing, conductors) to resist loading. Any loads applied to the platform beyond this level result in complete collapse and inability of the platform to resist the topside loadings.

The ULS capacity of a platform is difficult to obtain. Nonlinear methods are required to account for member behavior in the post-elastic, plastic range. The stiffness of the platform system must be continually monitored and updated as members enter the plastic or brittle (little or no capacity beyond elastic) regime. This differs from typical "elastic" design practices where elements behave in the linear regime requiring only one stiffness formulation at the beginning of the analysis.

There are two major outcomes of a ULS analysis. The first is the ULS capacity or maximum loading level that can be sustained by the platform (e.g. 2000 kips horizontal loading). The most simple representation of this is a force versus displacement plot (Figure 2-1).

The second major result is the study and identification of the platform's response to loading. This includes the sequence of member failures and the study of the platform's response to these failures in terms of alternate load paths and weak links in the system.

4.2 Analysis Solution Strategy

This project used the nonlinear program SEASTAR [4]. The program has a library of nonlinear elements particularly designed for limit state analysis. A recent addition to the program is a special solution strategy to determine the ULS capacity in AIM-type "push-over" analysis (i.e., the structure is "pushed over" until it fails).

Figure 4-1 shows how the process works for a simple truss frame. The loading is continually applied to the frame until a member reaches its elastic capacity. At this time, the load-carrying capacity of the frame reduces due to the loss of capacity from the failed member, as indicated by the dashed line to point A. However, instead of tracking the load reversal, the program maintains the load level (solid line) and continually displaces the frame until the frame can again resist loading (at a larger displacement) as shown by point B.

The process then follows the platform load path until the maximum capacity is reached at point C. At this point, most of the frame's elements have yielded and can no longer resist loads. The result is a dramatic decrease in load-carrying capacity as shown by the dotted line. The program maintains the maximum load level looking for a re-emergence of the platforms capacity at larger deformations. This does not develop, and the analysis is halted after a reasonable maximum credible displacement.

The solution strategy used by the program (solid line, Figure 4-1) to determine ULS improves upon other methods that track the actual platform load path (dashed line, Figure 4-1) since in reality, a wave will continually exert load on the system - as is the case for the program solution strategy. Similar to a wave, the program maintains load on the system and does not "back-off" load until the platform can again begin to respond (dashed line).

In addition, this type of solution technique is easier to control than load reversing techniques and results in a more automated process. In fact, the number of damage cases originally slated for this study was five, based upon using the method of load reversals. However, the efficiency of this new method allowed for a total of twelve damage cases for the project using the same schedule and budget.

4.3 Computer Model

Figure 4-2 shows a three dimensional view of the computer model and indicates the types of computer elements used throughout the platform. Also shown are the types of force-deformation characteristics for each type of element. A brief description of these elements is provided in the following:

SOILS - PSAS (Pile Soil Analysis System) elements [12]. These nonlinear elements reflect the axial and lateral force-deformation characteristics of soil-pile interaction. The shape and character of the curves follows the recommendations outlined in API RP 2A [6]. There are approximately 10 PSAS elements located along the piles and conductors.

PILES/CONDUCTORS - Nonlinear beam elements [13]. These elements reflect the elastic-plastic relationship for beam-columns that fail by yielding in both tension and compression (no buckling) bending and torsion. These members are likely to yield before buckling due to their heavy walls and the lateral support provided by the soils. The piles are rigidly connected to the jacket legs due to grouting. The conductors are laterally supported at the conductor guide but are free to move vertically.

JACKET LEG/PILE - Nonlinear beam elements. Same modeling as piles/conductors. The grouted leg/pile section through the jacket provides a sufficiently stiff section that precludes buckling.

DECK LEGS - Nonlinear beam elements. Bending at the top of jacket or the lower deck connection is the likely failure mode. This is adequately modeled by the nonlinear beam element.

BRACES - Struts [14,15]. The slender brace members are governed by axial loading with very little bending. They are also likely to fail in compression by buckling. Therefore, these members are most properly modeled by "strut" elements that carry only axial loads and exhibit a decay in post buckling capacity. When one of these elements has "buckled," the load that was carried by the member must be redistributed to nearby members since the buckled member is incapable of carrying significant loading.

DECK - Linear Beam Elements. Since the deck was modeled primarily to capture wave loads and to distribute loads between legs, the deck elements were modeled as linear beam elements. This implies that the deck elements stay within the linear regime throughout the analysis. This assumption was checked to ensure the deck elements behaved in a linear fashion. The leg members extending through the deck were modeled as nonlinear beams.

The steel material used throughout the platform is A36 with a nominal yield stress of 36 ksi. This yield value was upgraded by 12 percent to account for the difference between nominal and expected yield strengths [16]. Where available, original mill certification documentation can be used to determine the yield strengths of various members. The yield stress was increased by another 12 percent to account for strength increases due to strain rate effects [17]. The actual yield stress used in the analysis was therefore taken as 45 ksi (1.12 x 1.12 x 36 ksi). The intent of this modification is to account for actual in-service steel strength rather than allowable design values.

Tubular sizes assumed nominal specified diameters and wall thicknesses. In a real AIM evaluation, more complete data may be used such as mill material inspections (certifications) which detail the actual thickness of the member. This actual thickness should be equal to (or higher than) the nominal specified.

The brace members modeled with struts were checked to ensure the braces would not punch through the legs prior to buckling. This type of failure mode can be important for older structures without joint cans or grouted legs which were designed before much was known about joint punching. For this platform, the grouted leg-pile section provides adequate strength to ensure the member buckles first (i.e. the joint is stronger than the brace).

The buckling capacity of the braces was also modified to account for lateral wave loading. This concern decreases the buckling capacity due to lateral loads acting along the length of the member. Figure 4-3 shows the response for a typical brace and the effect of lateral wave loading. For this platform and these wave conditions (100-yr wave used to determine lateral load on brace), the buckling load is only slightly affected (less than 10%). For other platforms, the decrease in buckling stress may be more significant. For example, Platform "B" of AIM II [3] was in about 50 feet of water with a near breaking design wave. The geometry of the braces plus the high water particle velocities of the wave combined to reduce the buckling capacity on some braces by as much as 30%.

The conductors were modeled as three individual elements with each element representing eight conductors. This simplification is used to reduce the size of the computer model.

The interior horizontal framing was modeled in detail (except the conductor trays) to ensure the proper load paths for load redistribution once platform members fail. The typical approach of representing this framing with an equivalent "X" brace may result in improper load redistribution and hence was not used here.

4.4 ULS Capacity Determination

The ULS analysis uses the wave load profile developed in the environmental force computation (Section 3.4) to laterally load the platform to failure. Figure 4-4 shows how this process works.

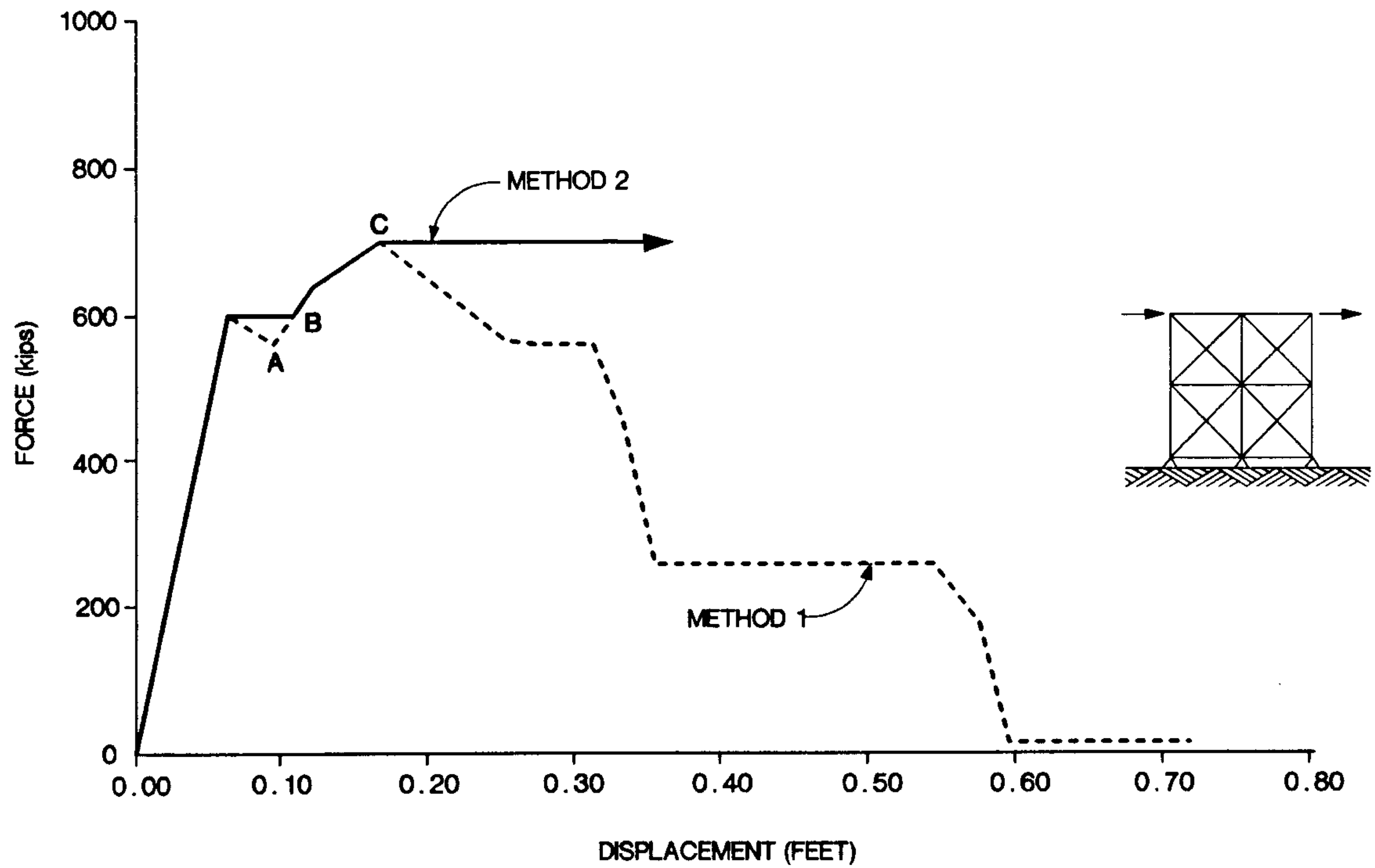
The first step is to apply the platform's deadweight and topside load onto the structural system. This establishes the inherent platform loading created from operations.

The second step is to apply the lateral load acting on the platform, using a load profile representing a wave with its crest located just below the deck. The magnitude of this load profile is continually increased (from a zero load condition) until the loading due to this wave is completely applied to the system. At this point the platform has survived the maximum wave that does not impact the deck.

The third step is the inclusion of deck wave loading into the lateral force profile. These loads are applied to the deck as point loads at the leg nodes. These loads plus the distributed wave loads on the jacket are then mutually increased until the platform fails. This loading represents conditions of large waves with crests impacting the deck structure and topsides equipment.

The ULS were determined for the platform's orthogonal directions - end-on (X) and broadside (Y). These are the primary loading directions that will affect buckling of the platform's brace. The buckling occurs parallel to the direction of the loading and will likely control ULS capacity. In a more complete AIM program, ULS capacity should be checked from a variety of directions (e.g. diagonal).

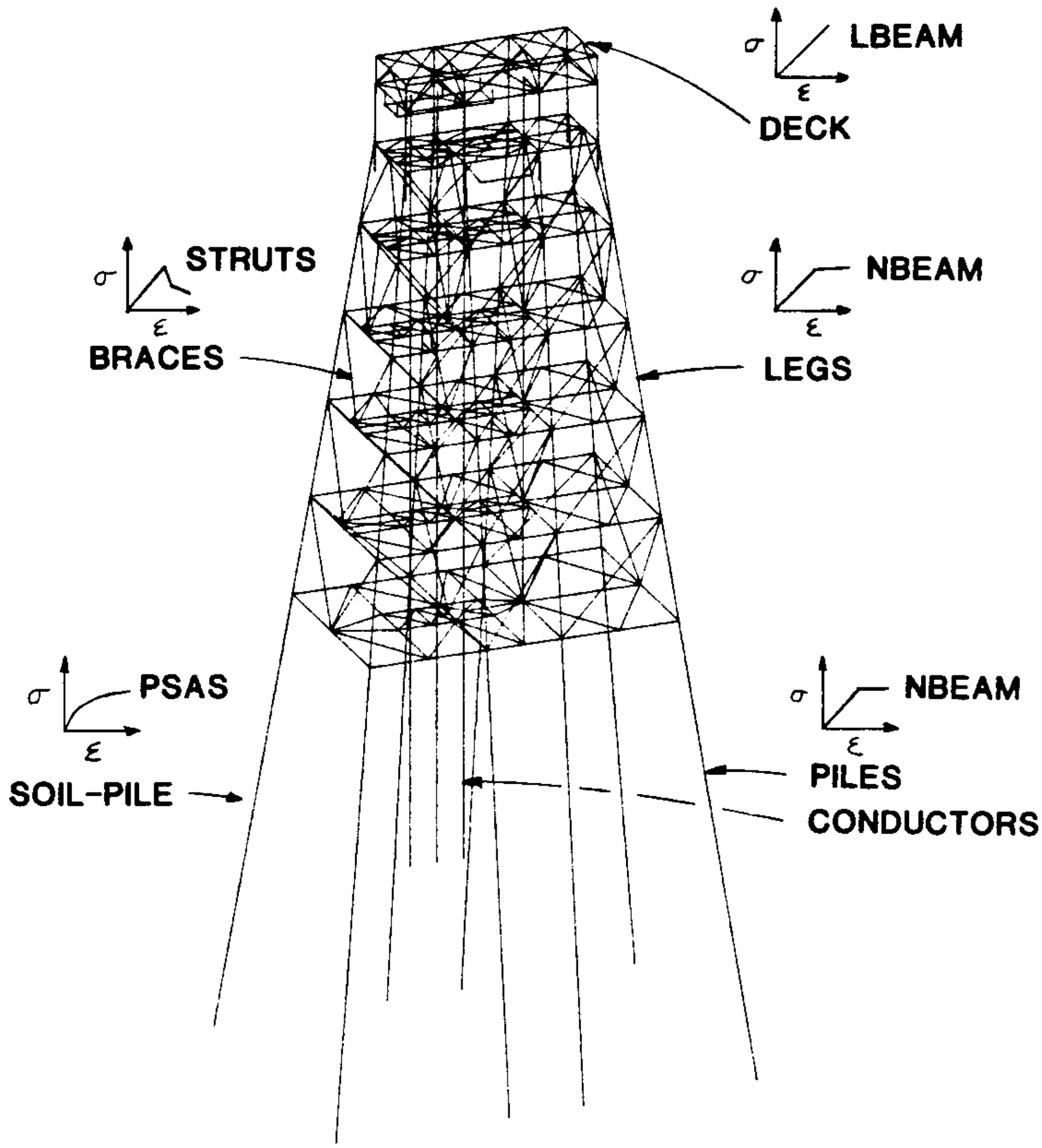
This is the general methodology used for the ULS analysis in the AIM III project. Variations of this procedure are required depending upon platform and wave conditions.

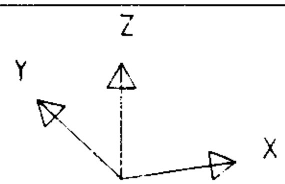


ULTIMATE LIMIT STATE (ULS) ANALYSIS

FIGURE 4-1

PMB Systems Engineering Inc, San Francisco, Calif. 94111





GLOBAL AXES

NONLINEAR COMPUTER MODEL

FIGURE 4-2

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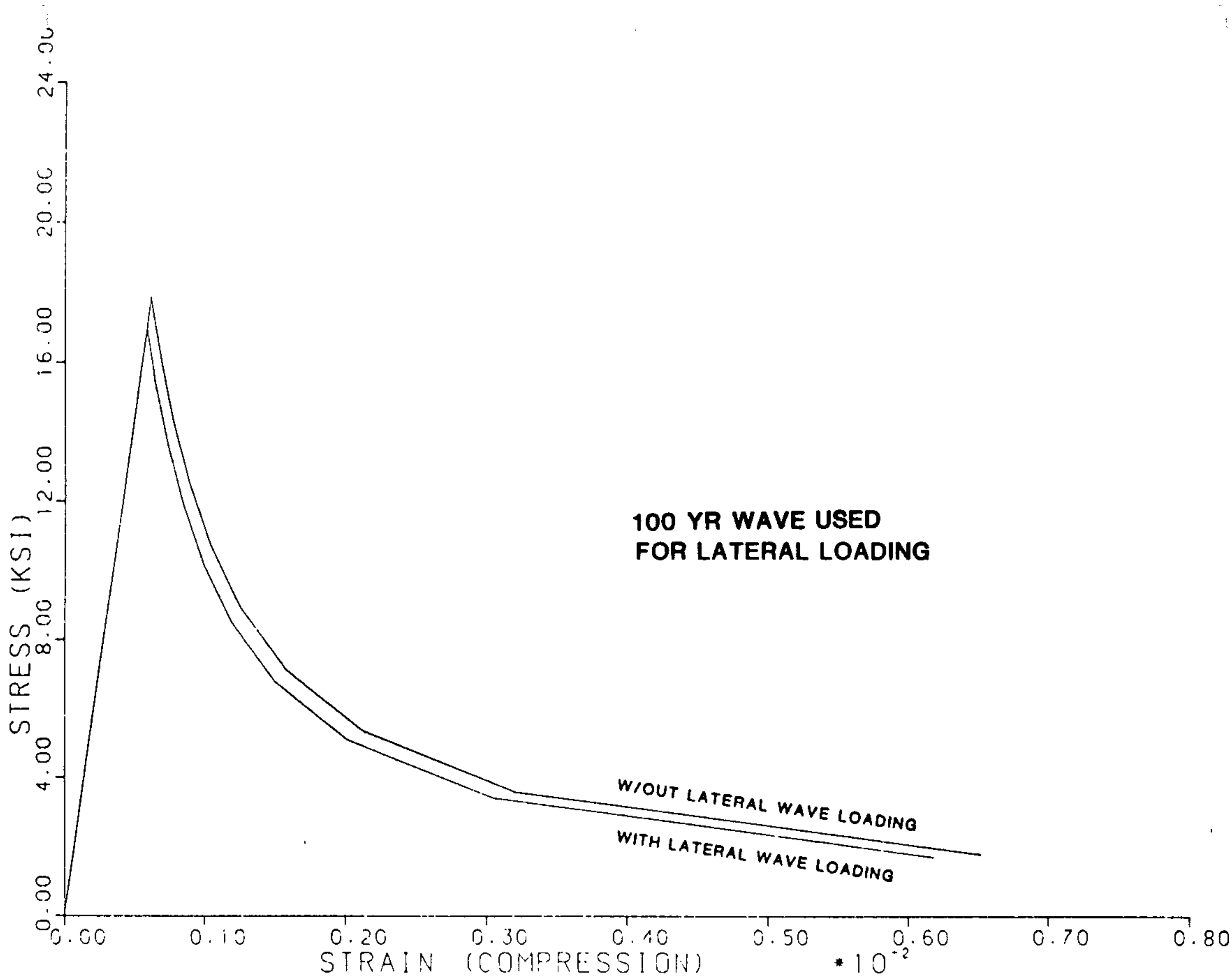
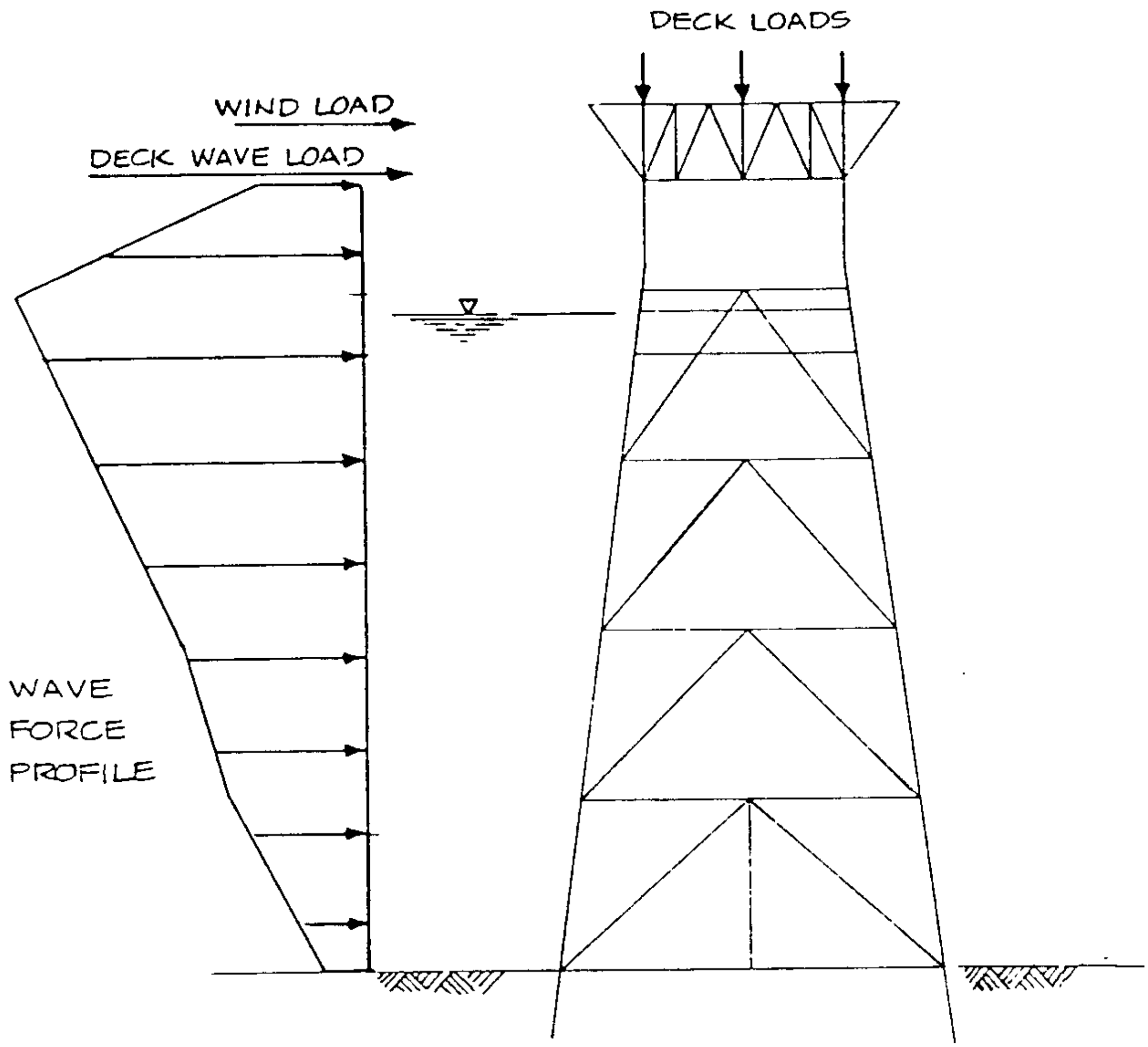


TYPICAL BRACE BUCKLING RESPONSE

FIGURE 4-3



FORCES ACTING ON PLATFORM FOR ULS ANALYSIS

FIGURE 4-4

5.0 INTACT CONDITION ASSESSMENT

5.1 Analysis Cases

The platform was analyzed for three major directions of wave loading (Figure 5-1): two end-on (+X, -X) and one broadside (Y). Two end-on conditions were required due to the unsymmetric platform geometry in this direction. For the +X direction two of the three braces along rows A or B would be in tension. For the -X direction these two braces would be in compression. Since tension capacity of the braces is higher than compression capacity (due to buckling) it is anticipated that the platform will be stronger in the +X direction (two braces in tension). Only one broadside condition was considered due to the platform's symmetric geometry (forward-backward) in the Y-direction.

For each of these cases, the platform was loaded to failure considering a wave acting below the deck and a wave acting on the deck. This results in a total of six analysis cases for the intact capacity assessment.

The evaluation considering a wave acting below the deck provides a simple first order estimate of the platform's capacity without the complication of accounting for wave impact of deck members and equipment. For this platform, the 100-yr return period wave was selected for the load profile since this is the maximum wave that acts on the platform without impacting the deck. The load profile was continually applied to the jacket until the platform reached its ULS capacity. This occurred at about the load level (base shear) equivalent to a 200-yr return period wave.

For the evaluation considering the wave impacting the deck, the goal is to have the most realistic load profile acting on the platform at the time of failure. Therefore, based upon the results of the evaluation for a wave acting below the deck, a 200-yr return period wave was used to generate the load profile acting on the jacket. The wave impact loads on the deck were computed by hand calculations, as described in Section 3.4, and applied to the deck at the eight leg nodes.

The analysis for waves impacting the deck proceeded as follows. The 200-yr wave load profile acting on the jacket was increased until the lateral load applied to the platform was equivalent to the 100-yr wave load. This simulates loads acting on the platform for wave crests less than the lower deck elevation. For loading beyond this point, the deck wave loads were added to the lateral load profile. These loads were small at first, and then increased as the loads acting on the jacket (200-yr load profile) were increased. The jacket and deck loads were increased at different rates (the deck load increases faster than the jacket load) to properly simulate the increase in loading with larger waves.

The following sections describe the results of the six analyses for the intact condition.

5.2 End-On Loading: +X Direction

This is the condition were two of the three braces along Rows A and B are in tension during loading. Figure 5-2 shows results of the analysis for wave loading both below and in the deck. The ultimate capacities are 2776 kips and 2736 kips, with the wave in the deck condition resulting in the lower capacity, as expected. Also shown are the sequences of member failures indexed to the associated sketches of the platform. The Reserve Strength Ratio (RSR) for this condition, defined as platform capacity divided by reference level load, varies between 1.5 to 1.7, considering a 100-yr wave as a reference load and a C_d ranging from 0.6 to 0.7.

The platform responds in a linear fashion until the onset of member failures. The slight offset of the platform at zero loading is the result of the platform and topside deadweight distribution. The change in the slope of the platform response for the wave in the deck condition is due to the application of the wave loads on the deck elements. These loads applied high up on the structure cause a larger deck displacement per load increment than loads applied to the lower elevations on the jacket.

The deck displacement reached about 1.2 feet at the time when there was a sufficient number of failed members to consider the platform in an unserviceable condition with collapse imminent. The analysis was halted at this time.

The general response of the platform is elastic-plastic indicating a brittle strength behavior and little redundancy (defined here as capability of other members to carry loadings of failed members). This is a typical result for K-braced platform systems like Platform "C" [18].

For the both loading cases, the first member fails in compression at a load level of about 2400 kips or about 87% of the ULS capacity. This member is located in the lower section of the jacket along Row B. The remaining member failures are different for the two cases, with failures located near the center of the jacket for wave loading below the deck, and failures located near the waterline for wave loading in the deck. This is as expected given the large loading high up on the platform for wave loading in the deck. All of the member failures were for an axial mode located in the braces with no bending failures in the deck legs or piles.

One of the reasons for brittle behavior are the weak horizontal elements of this platform. Once the compression brace fails in a bay, the two tension braces are sufficient to carry the loading of the lost member. However, the load path required relies on the interconnecting horizontal. If these should also fail, the load path to the tension braces from the failed compression brace is interrupted, incapacitating the tension brace from picking up the extra load. The result is an ineffective bracing scheme with low redundancy. If the horizontal braces were stronger, then the platform would likely act in a more ductile, redundant fashion, similar to an X-braced framing scheme. This is an important point to consider in new platform designs. A small amount of steel put into strengthening horizontals may have a significant impact on platform redundancy.

From another viewpoint, the original platform designer appears to have done an efficient design of the platform on an elastic basis. In other words, many of the members reach their capacity at the same time, indicating the original designer optimized member sizes so that most members had an interaction ratio (design load divided by allowable load) of 1.0, saving steel and thus money for his client. The platform may have been designed differently by today's standards where ductility and redundancy might be incorporated into the design.

Appendix A provides some additional miscellaneous results of this analysis such as mudline displacements, vertical displacements, resistance contribution of conductors and loads in interior horizontals.

5.3 End-On Loading: -X Direction

This is the condition were two of the three braces along Rows A and B are in compression during loading. Figure 5-3 shows results of the analysis for wave loading both below and in the deck. The ultimate capacities are 2747 kips and 2607 kips, with the wave in the deck condition resulting in the lower capacity, as expected. Also shown are the sequences of member failures indexed to the associated sketches of the platform. The Reserve Strength Ratio (RSR) for this condition varies between 1.4 to 1.7.

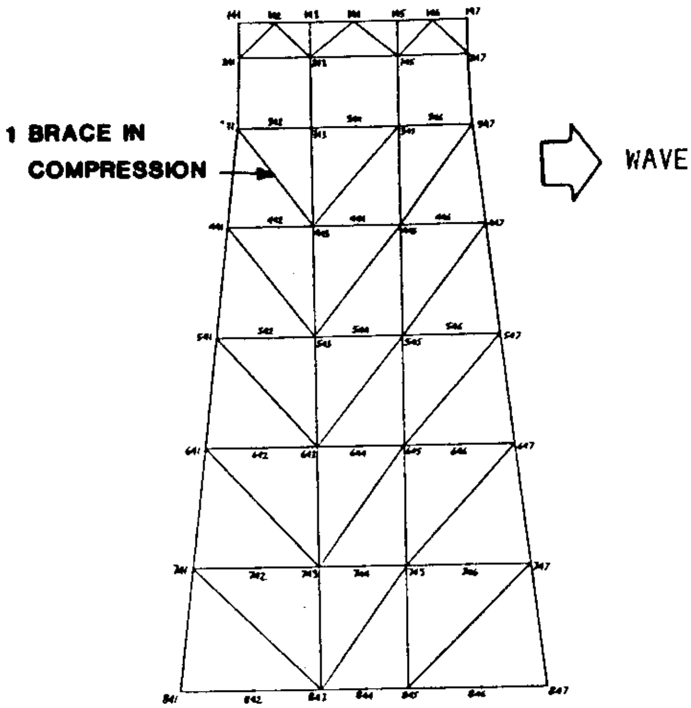
The platform's capacity for this end-on direction (compression braces) is lower than for the other end-on direction (tension braces). This is particularly true for the condition of wave loading in the deck. The member failure sequence reflects the same trends as the other direction, with failures concentrated higher in the jacket for the condition of wave loading in the deck. Most of the member failures are for an axial mode in the braces, however, there are some deck leg failures late in the analysis for the condition of wave loads in the deck.

5.4 Broadside Loading: Y Direction

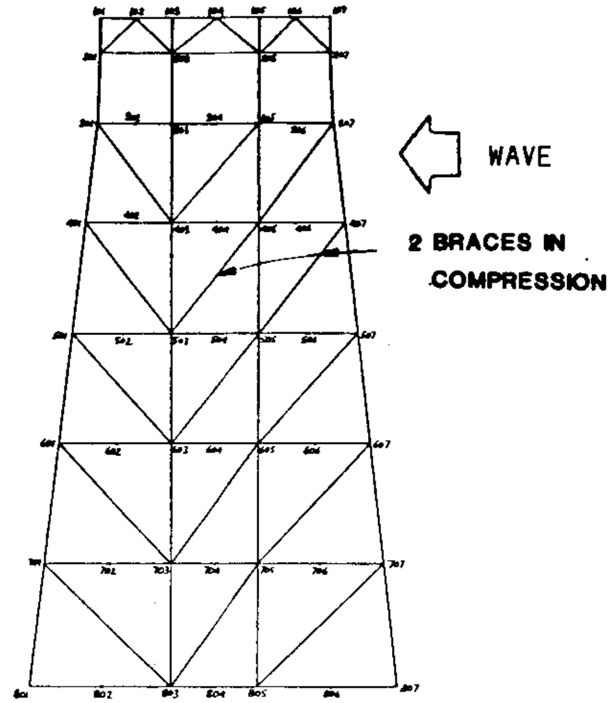
This is for the direction were the platform has forward-backward symmetry. Figure 5-4 shows results of the analysis for wave loading both below and in the deck. The ultimate capacities are 2755 kips and 2935 kips, with the wave in the deck condition actually resulting in a higher capacity. This is further discussed below. Also shown are the sequences of member failures indexed to the associated sketches of the platform. The Reserve Strength Ratio (RSR) for this condition varies between 1.2 to 1.6.

The platform responds in a brittle mode (elastic-plastic) attributable to the lack of redundancy through a bay. In other words, once the compression brace fails the single tension brace must take the loading, via the horizontal braces. The compression braces fail in rapid succession, eliminating much of the load carrying capacity of the platform. All of the member failures were for an axial mode in the braces.

Figure 5-5 helps explain why the wave in the deck capacity was higher than the wave below the deck capacity. Recall, that each of these analyses used a different wave load profile with the wave below the deck condition using a 100-yr wave profile and the wave in the deck condition using a 200-yr wave load profile. Figure 5-5 shows the cumulative shear (at time of platform failure, summing from the deck downward) acting on the platform at each horizontal elevation. Above the waterline, the 200-yr (wave-in-deck) condition imparts greater shear on the platform than the 100-year (wave below deck) condition. This situation is reversed below the waterline. Since the platform failures are centered below the waterline, the greater loads (acting below the waterline) of the 100-yr (wave below deck) condition result in failure at a lower total (entire platform) load level.

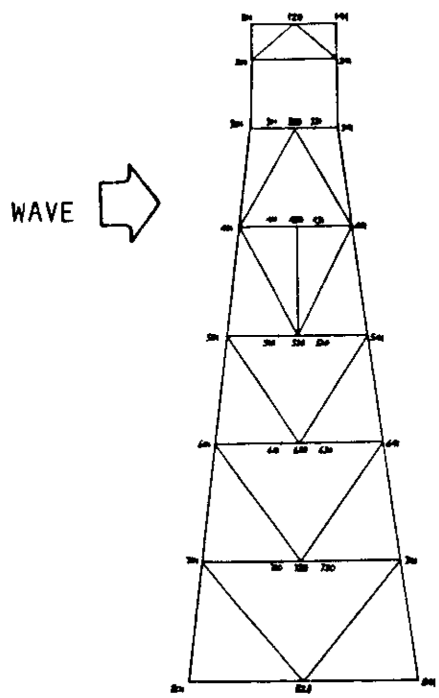


X DIRECTION



X DIRECTION

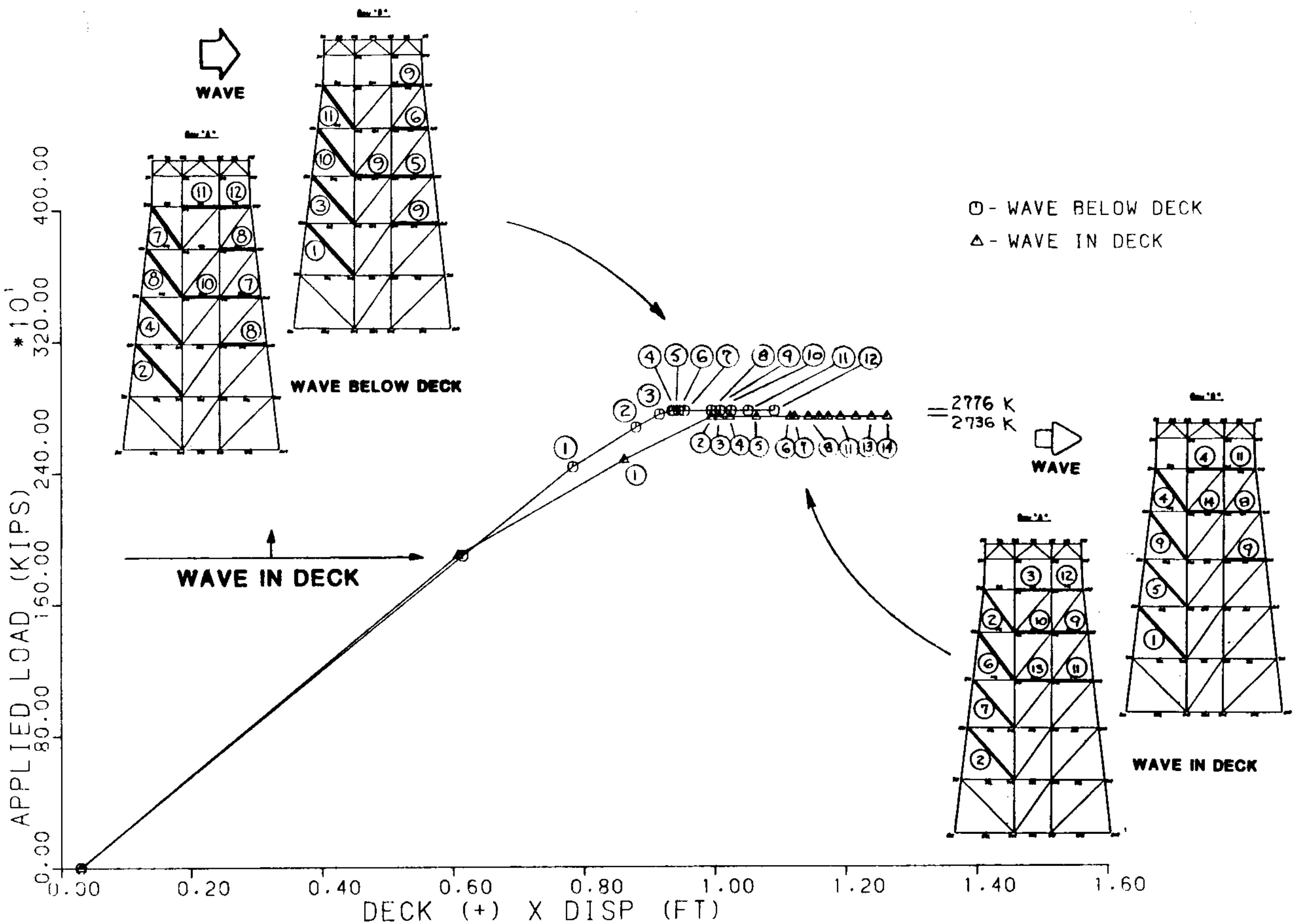
END-ON



BROADSIDE

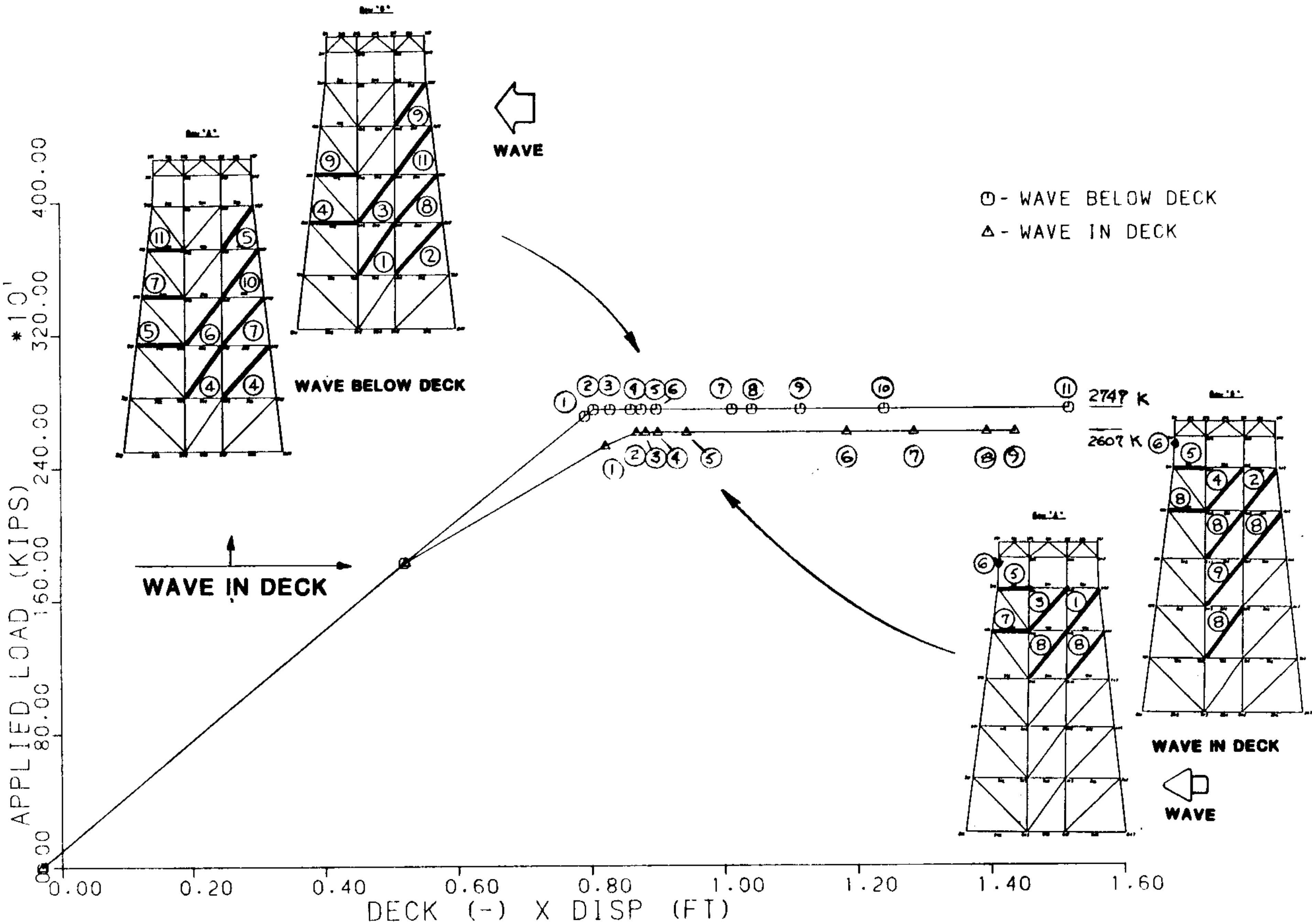
INTACT ANALYSES CASES

FIGURE 5-1



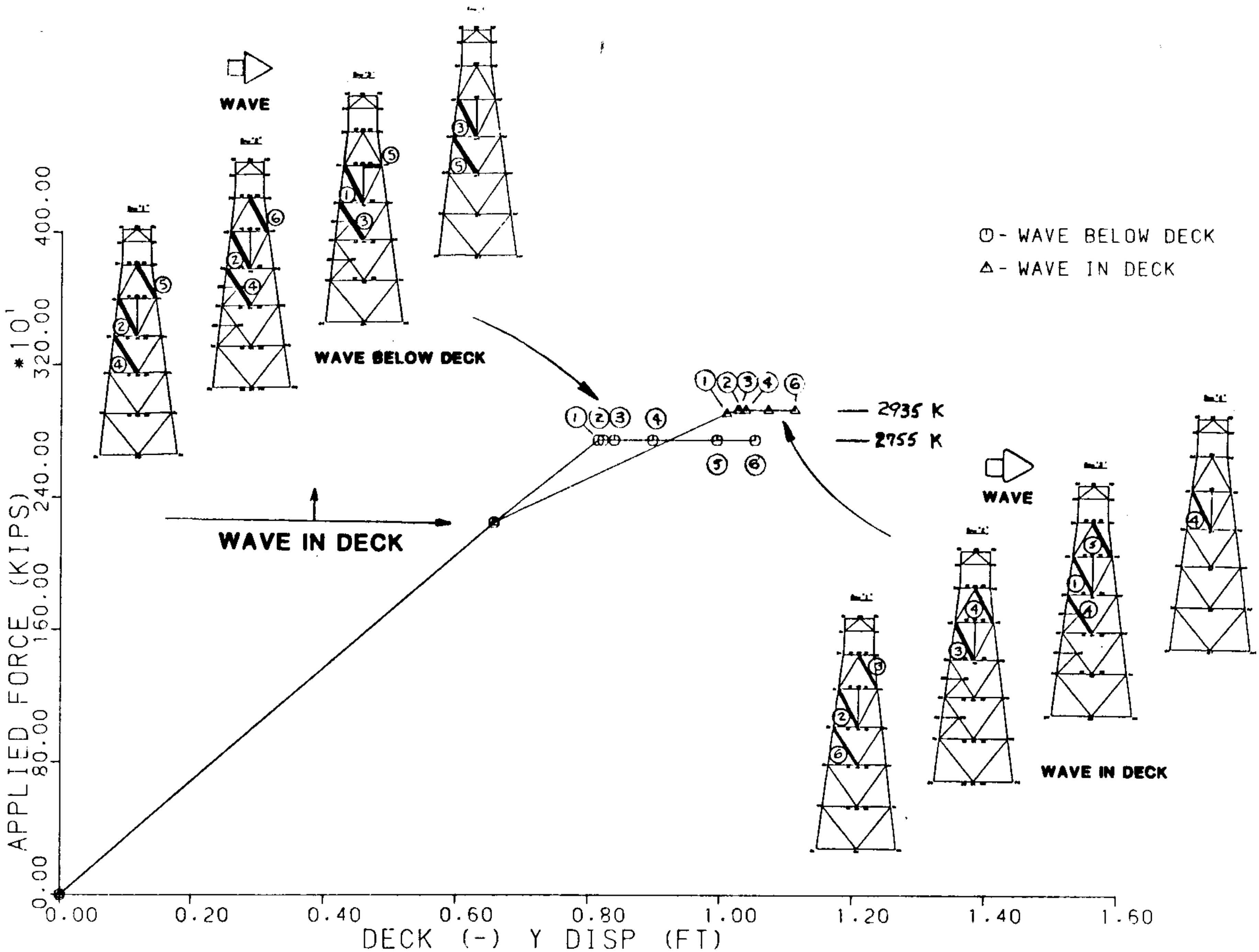
INTACT CONDITION - END-ON LOADING: +X-DIRECTION

FIGURE 5-2



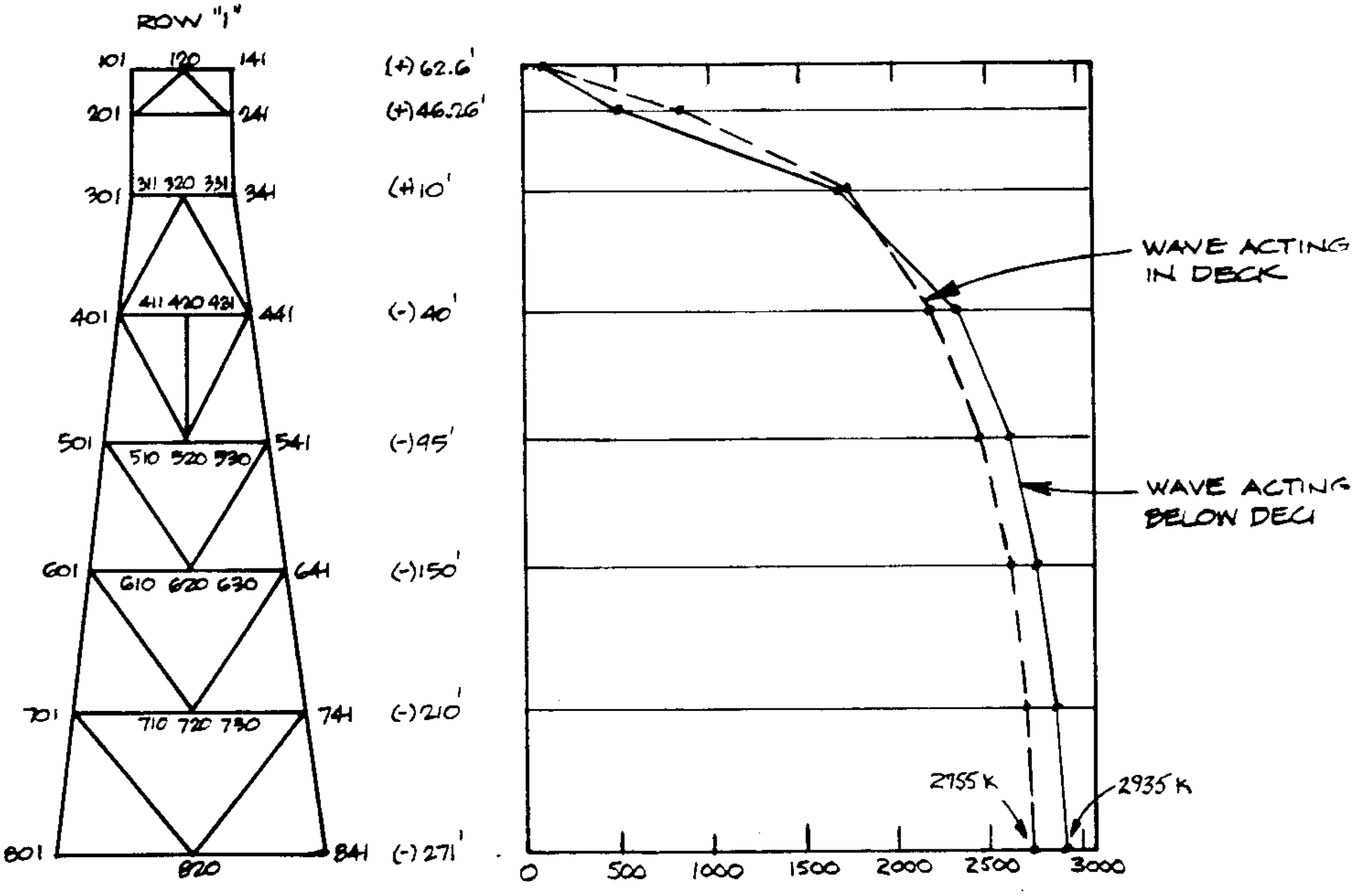
INTACT CONDITION - END-ON LOADING: -X-DIRECTION

FIGURE 5



INTACT CONDITION - BROADSIDE LOADING: Y-DIRECTION

FIGURE 5-4



COMPARISON OF 100-YEAR VS. 200-YEAR WAVE LOAD PROFILES

FIGURE 5-5

6.0 DAMAGED CONDITION ASSESSMENT

6.1 Summary of Damage Cases

The damage cases were selected based upon participant input. A total of twelve damage cases were analyzed, considering five basic categories of damage conditions. These basic categories are shown in Figure 6-1 with the details and results of each described in the following sections. A brief description of each category is as follows:

Damaged Members Near Waterline: Horizontal and diagonal members were considered dented and bent as a result of work boat impacts. The damage was considered localized around the boat landings. A reduced member capacity was used to model the damage.

Damaged Members Near Base of Jacket: Horizontal and diagonal members were considered broken (severed) by falling debris (e.g. drill pipe) from topside operations. The damage was in the area of the conductors. The members were eliminated from the computer model to simulate the damage.

Interior Horizontal Damage: This damage considered the loss of several interior horizontals and damage (denting, bending) to a main diagonal along Row 1. The damaged was assumed to occur as a result of falling debris from topside operations.

Corrosion Damage: Two types of corrosion damage were considered. The first focused upon corrosion throughout the entire jacket for all members at and below the +10-ft horizontal elevation. The corrosion damage was modeled by reducing the member wall thicknesses in this region by 1/8 inch. The second focused upon severe, but localized, corrosion in the splash zone from the mean water line to the +10-ft horizontal elevation. For this case the corrosion damage was modeled by reducing the leg thicknesses by 1/4 inch and the brace thicknesses by 1/8 inch.

Foundation Defects: This type of damage is considered a "defect" occurring during platform installation instead of "damage" occurring during platform operations. For this case, the two piles along Row 1 met early refusal, resulting in 120 ft (out of 270 ft) of underdriven piles.

An additional condition was studied outlining a refined approach to determining wave loads on deck elements. Since this condition is not directly related to a damage case, it is discussed separately in Section 7.0.

6.2 Damaged Members Near Waterline

6.2.1 Damaged Member Modeling

There are two types of damaged members considered by this study: severed members and dented/bent members. The computer modeling for each is described in the following paragraphs.

Severed members are unable to transmit axial, shear, bending or torsion loadings. The member is considered severed due to several types of damage conditions. Examples are a complete severance due to debris impact, a through crack around most or all of the member or perhaps large corrosion holes. Computer modeling of this condition is handled by elimination of the element representing the damaged member from the computer model.

Dented and bent members are more difficult to model, since the member's load carrying capacity has not been completely eliminated. The conservative approach is to eliminate the member from the computer model; however, for most AIM evaluations there is a need to rely on all of the platform's components, including damaged members and secondary support elements such as launch trusses, to obtain the most accurate ULS capacity. Therefore, there is a need to adequately account for the strength contributions of damaged members.

There are several laboratory studies available for estimating the strength of dented and bent members [19,20,21]. For this study, the results of the DENTA project [19] have been used to determine the strength of the damaged tubulars. The project consisted of laboratory testing of small diameter tubulars (4 to 10-inch diameters) with simulated dents and bends. The results of the project were used to develop a computer program known as DENTA that could be used to determine changes in damaged member strength according to key parameters such as member diameter, length, dent depth and bending offset. For this study, a series of nondimensional nomographs developed using DENTA were used to determine the required changes in member strength for the assumed damaged conditions.

Figure 6-2 shows the results of using the DENTA nomographs to determine the strength of the damaged horizontal for Platform "C". A range of potential damage conditions was first considered, such as a 3-inch dent depth and a 1/2-inch bending offset. The results indicated that the member's capacity quickly reduces to about one third of its undamaged capacity with little inflicted damage. A final damage state for the horizontal was selected for a dent depth of 2 inches and a bending offset of 3 inches. The dent depth is in the range of actual dents observed by divers for the AIM II platforms [3]. The bending offset translates to a deflection of 1/120 which is about the magnitude that is visible to the naked eye. Based upon these damage conditions, the damaged brace capacity drops to 35% of the undamaged condition.

DENTA results were also used to determine strength reduction for the damaged diagonal. The final damaged state for the diagonal is the same as for the damaged horizontal (2 inch dent, 3 inch bending offset). The damaged brace capacity for this condition is 40% of the undamaged condition.

This study used only the DENTA results to model dented and bent members. Other test results are available, as noted earlier, and should be used when appropriate. There is some concern that the DENTA results underpredict the damaged member's strength (i.e. the damaged member is actually stronger than determined by DENTA); however, the further investigation of damaged member capacity is beyond the scope of this study. As shown later, the damaged members had only minor effects on Platform "C"'s ULS capacity, indicating the capacity is insensitive to the DENTA results. This may not always be the case for other platforms.

6.2.2 Damaged Horizontals

This case considered two damaged horizontals along Row A at elevation +10 ft. The analysis was performed in the end-on -X direction which is parallel to the damaged members and is the weakest X direction with two braces in compression at each bay. The load profile for a wave acting in the deck was used for the analysis.

Figure 6-3 shows the results of the analysis compared to the platform's response in an undamaged condition. The ULS capacity of the platform decreases by about 11 percent. The first member to fail is one of the damaged horizontals at a very low load level. The remaining member failure sequence is more concentrated near the waterline than for the undamaged condition (Figure 5-3). This is due to the reduced capacity of the jacket in this region created by the damaged braces. There are also some deck leg bending failures later in the analysis that were not present for the intact condition.

The RSR for this damaged case ranges between 1.3 to 1.5. Overall, the damaged horizontals had a minimal (less than 70 percent) effect upon the platform's capacity. A capacity reduction of less than 20 percent is probably a "minimal" effect for this platform. The platform's undamaged RSR is about 1.5 and a 20 percent capacity reduction will not reduce the

RSR to a level requiring immediate attention (e.g. evacuate platform and emergency repair). Higher load reductions such as 30 to 40 percent are more serious since the resulting RSR is around 1.0, which is a "marginal" value for Platform "C" [1]. Note that the definition of "marginal" varies between platforms. A 20 percent reduction in capacity for a platform with an already low RSR may be serious.

6.2.3 Damaged Diagonal

This case considered a single damaged diagonal along Row A located just below the +10-ft horizontal elevation. This analysis was also performed in the weak end-on -X direction using the load profile for a wave acting in the deck. Figure 6-4 shows the results of the analysis compared to the platform's response in an undamaged condition.

The ULS capacity of the platform decrease by about 10 percent. This decrease is slightly less than that for the two damaged horizontals of the last case due. This may not have been the case if only one horizontal had been considered damaged. The damaged diagonal is again the first member to fail with subsequent member failures concentrated near the waterline. Deck leg bending failures are evident later in the analysis.

The RSR for this damaged case ranges from 1.3 to 1.5. Similar to the damaged horizontals, the damaged diagonal had a minimal effect upon the platform's capacity.

6.2.4 Damaged Horizontal and Damaged Diagonal

This case considered a damaged horizontal and a damaged diagonal along Row A located just below the +10 ft horizontal elevation. This analysis was performed in the weak end-on -X direction using the load profile for a wave acting in the deck.

Figure 6-5 shows the results of the analysis compared to the platform's response in an undamaged condition. The ULS capacity of the platform decreases by about 6 percent. This is surprisingly less than for either the damaged horizontal or the damaged diagonal condition. Further investigation indicated that Row B elements carried more load than for previous analysis due to the combined horizontal-diagonal damage in Row A. This can be seen in the member failure sequence. For the previous damaged conditions (Figures 6-3 and 6-4), the first failure of an intact member is the center diagonal on Row A below the +10 ft horizontal elevation. The loss of this member along with the original damaged member severely penalizes the platform's strength along Row A, while Row B still contains all intact members. For this combined damaged condition (Figure 6-5), the first failure of an intact member occurs along Row B, resulting in approximately equal capacity along Rows A and B. The overall effect is a slight increase in capacity for the system. Thus, the platform's geometry and selection of the damaged members plays a crucial role in the estimate of platform capacity.

The RSR for this damage case ranges from 1.3 to 1.5. Again, the effect of this damage on the platform's capacity appears minimal.

6.2.5 Damaged Horizontal and Damaged Diagonals

This case considered a damage horizontal and two damaged diagonals along Row A located just below the +10 ft horizontal elevation. The analysis was performed in the weak end-on -X direction using the load profile for a wave acting in the deck load profile.

Figure 6-6 shows the results of the analysis compared to the platform's response in an undamaged condition. The ULS capacity of the platform decreases by about 15 percent. This strength reduction is more than for the previous damage cases. The two weakened diagonals eliminate a large proportion of the capacity near the waterline along Row A.

The RSR for this damage case ranges from 1.2 to 1.4. Although the capacity reduction has increased to 15 percent, this is still not a major loss of platform capacity.

6.3 Damage Near Base of Jacket

6.3.1 Damaged Horizontal

This case considered a damage horizontal near the base of the jacket caused by falling debris. The damaged member was considered to be completely severed and was simulated by removing the member from the computer model. The analysis was performed in the weak end-on -X direction using the load profile for a wave acting in the deck.

Figure 6-7 shows the results of the analysis compared to the platform's response in an undamaged condition. The ULS capacity decreases by about 10 percent. The member failures are centered around the missing horizontal. This differs from the intact case where the member failures were centered around the waterline as a result of wave loading in the deck (Figure 5-3). It is interesting that the platform's capacity is not severely effected even though the concentration of member failures has moved to a different location on the platform.

The RSR for this damage case is in the range of 1.3 to 1.5. This damage does not appear to significantly affect the platform's capacity.

6.3.2 Damaged Diagonal

This case considered a damaged diagonal near the base of the jacket also caused by falling debris. The damaged member was considered to be completely severed and was simulated by removing the member from the computer model. The analysis was performed in the weak end-on -X direction using the load profile for a wave acting in the deck.

Figure 6-8 shows the results of the analysis compared to the platform's response in an undamaged condition. The ULS capacity decreases by about 12 percent. This is a greater decrease than for the damaged horizontal in the same region. The member failures are again centered around the missing member.

The RSR for this damage case is in the range of 1.2 to 1.4. As for the missing horizontal condition, this damage does not appear to significantly affect the platform's capacity.

6.4 Interior Horizontal Damage With Diagonal Damage

Based upon the results of the previous analysis cases, an additional case was selected using interior horizontal damage combined with damage to a diagonal along Row 1. The interior horizontals were considered severed, and were simulated by removing the members from the computer model. The damaged diagonal was considered dented 2 inches and bent 3 inches which is the same damage as the previous Row A diagonals. This damage decreases the diagonal's strength to 40 percent of its strength in the undamaged condition.

Figure 6-9 shows the results of the analysis compared to the platform's response in an intact condition. The analysis was run in the broadside Y-direction using the load profile considering waves impacting the deck. The ULS capacity takes a significant decrease of 21 percent indicating a more severe damage condition than the previous cases.

Study of the analysis results indicate the major contributor to capacity reduction is the missing diagonal and not the interior horizontals. The loss of a diagonal along Row A did not significantly affect the platform's capacity as exemplified by the previous cases. But the loss of a diagonal along Row 1 appears to significantly impact capacity. This can be seen in the platform's response plot at the point of failure of the damaged diagonal were the response flattens, indicating a significant decrease in platform stiffness and the importance of this member. This flattening of response is more severe than was seen in the other damaged cases (Figures 6-5 and 6-6).

The RSR for this damage case ranges from 1.0 to 1.3. The low level of the RSR indicates some concern that in this damaged condition, the platform may not survive the 100-yr design wave. This damage is probably beyond the type that could be considered "minimal."

6.5 Corrosion Damage

6.5.1 Corrosion Modeling

The corrosion was modeled by revising the strength properties of the affected elements to account for a decrease in tubular wall thickness. This meant a revised capacity for buckling and yielding for the braces and revised bending capacities for the legs.

Figure 6-10 shows a typical member force-displacement relationship for a corroded brace compared to an intact brace. The corrosion considers a 1/8 inch loss from the brace's wall thickness. The buckling capacity of the brace decreased by about 30 percent due to the corrosion material loss. Since this type of capacity reduction will occur throughout the jacket, the corrosion condition is expected to significantly affect the platform's capacity.

Figure 6-11 shows a typical member force-displacement relationship (measured as a moment-rotation) for a corroded deck leg (elevation +10 ft) compared to an intact deck leg. The capacity is reduced by about 30 percent to account for the 1/4-inch corrosion in the splash zone.

The grouted leg-pile member in the jacket was similarly reduced in strength for corrosion. The capacity reduces by about 8 percent for 1/8-inch corrosion and 13 percent for 1/4-inch corrosion. The 1/4-inch corrosion will be used for the splash zone corrosion condition.

6.5.2 General Jacket Corrosion - Broadside Loading

All of the platform's members below the waterline were modified according to the 1/8 inch corrosion damage condition. The analysis was run in the weak -Y direction using the load profile considering a wave impacting the deck.

Figure 6-12 shows the results of the analysis compared to the intact platform condition. The ULS capacity of the platform decreases by about 32 percent. This is a significant reduction, with the resulting in capacity below the loading level of the 100-yr wave. The member failure sequence is different from the intact condition (Figure 5-3) with the member failures centered near the midpoint of the jacket instead of near the waterline.

The RSR for this damage case ranges from 1.0 to 1.1. The low level of the RSR indicates some concern that in this damaged condition, the platform may not survive the 100-yr design wave. This is a serious damage condition which will probably require some remedial action.

6.5.3 General Jacket Corrosion - End-On Loading

Damage conditions for this case are the same as the previous case except the analysis was run in the X-direction considering wave loads impacting the deck.

Figure 6-13 shows the results of the analysis compared to the intact platform condition. The ULS capacity of the platform decreases by about 34 percent. Again, this is a significant reduction in capacity. The member failure sequence for this case is quite similar to the intact condition (Figure 5-4).

The RSR for this damage case ranges from 0.9 to 1.0. The low level of the RSR indicates that in this damaged condition, the platform will not survive the 100-yr design wave. This is a serious damage condition which will probably require some remedial action.

6.5.4 Splash Zone Corrosion

This case modified the member properties of elements in the splash zone to account for severe corrosion. The splash zone was defined as all elements between the top horizontal located at +10 ft and the waterline. The base of the deck leg just above +10 ft was also considered to be corroded. The corrosion was taken as 1/4 inch for the legs and 1/8 inch for the braces. The design corrosion allowance for braces in this zone was included when taking the decrease in wall thickness.

The analysis was run in the broadside Y-direction considering wave loads impacting the deck. This direction was selected since the platform had shown the largest capacity decrease in this direction when considering corrosion.

Figure 6-14 shows the results of the analysis compared to the intact condition. The ULS capacity of the platform decreases by about 18 percent. Member failures were located more towards the waterline than for the intact condition (Figure 5-4), reflecting the decreased member capacities in this corroded region.

The RSR for this damage case ranges from 1.1 to 1.3. The damage reduction is approaching a value that is more serious than "minimal." The reduction in platform capacity is more severe than that determined for the damaged individual members.

6.6 Foundation Defects

6.6.1 Underdriven Pile Condition

This damage case assumes that the two piles along Row 1 met early refusal during installation. This poses two major problems for the platform. The first is a significant decrease in pile axial capacity possibly forcing failure of the platform to occur in the foundation instead of in the jacket as demonstrated in the previous damage cases. The second concern is the loss of the heavy wall pile section near the mudline. This heavy wall section will now be contained within the jacket leg with a lighter pile section just below the mudline where bending moments are the greatest. Both of these problems can combine to cause severe problems for the platform. The first task in this evaluation was to pick a damaged pile penetration that was both realistic and would provide interesting results.

Figure 8-15 shows the pile capacity curve differentiating skin capacity and total capacity (including tip bearing). The total capacity curve shows the typical increase with depth until the pile penetrates the clay layer at about 250 ft below the mudline. The sudden decrease in total capacity when the pile reaches the clay layer is due to the loss of the large tip bearing available in the sand layers.

Also indicated on Figure 6-15 are the different primary soil layers. There are four primary soil layers, with a variety of sand layers overlying a stiff clay layer. Figures 3-7 and 3-8 contain more details regarding the soil profile.

Checks of the loading in piles A1 and A2 for the intact condition indicated axial loads at time of platform failure in the range of 3300 to 3800 kips. This range is indicated on Figure 6-15.

Based upon this background data, the pile was configured to met refusal at a penetration of 150 ft. This is about the location of a change in sand layers 2 and 3, and it is plausible that the sand is very dense, making driving difficult, and eventually forcing pile refusal. In addition, the total pile capacity has been reduced to a level at about the same loading as seen for the intact condition.

Therefore, the pile may "plunge" during the ULS analysis as it reaches its capacity and forces load redistribution to the other piles. This 120 feet of underdrive will also result in a 7/8 pile wall thickness near the mudline instead of the 1 5/8 wall thickness of the original design (see Figure 3-5 for pile makeup).

6.6.2 Damaged Foundation - Broadside Loading

Figure 6-16 shows results of this analysis using the load profile for a wave impacting the deck. The ULS capacity has been reduced by only about 5 percent. The RSR for this case ranges from about 1.2 to 1.5. The damaged piles did not plunge or was there any bending or axial loading problems in the smaller pile section near the mudline, although the pile stresses were above the allowable per API [6].

Further investigation of the load history of the analysis explains these results. As the platform system is first loaded, load is distributed to each of the piles according to each pile's relative stiffness. Since the damaged piles are less stiff that the intact piles, the damaged piles attract less load and the intact piles attract more load than for an undamaged condition.

This is illustrated in the Figure 6-17 which compares the loading history of the piles in the intact and damaged condition. Damaged Pile A1 takes less load (plotted as a function of the lateral deck displacement) for the damaged condition than for the undamaged condition. Intact Pile A2 takes more load for the damaged condition than for the undamaged condition.

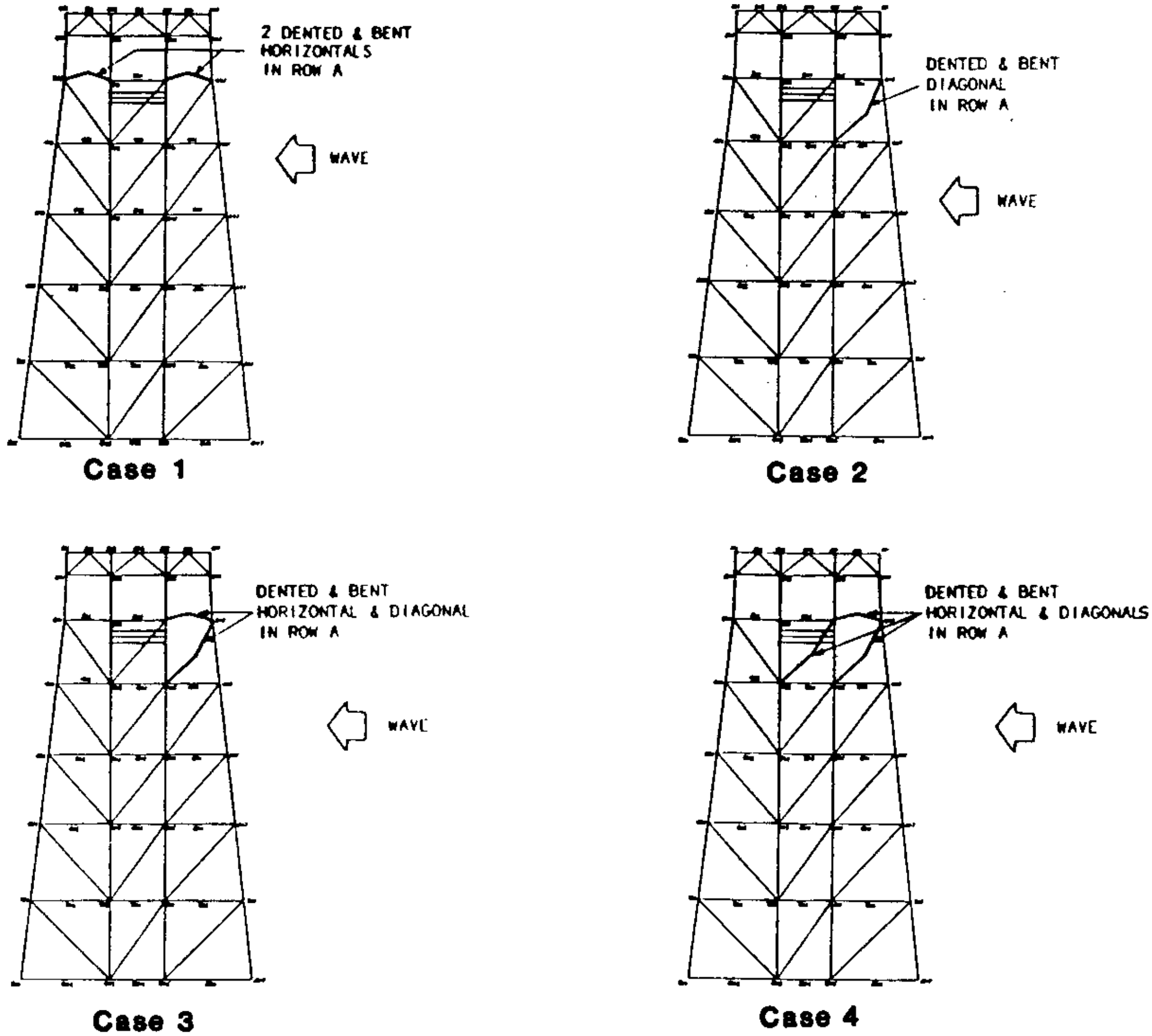
Given that this damage or defect occurs at the beginning of a platform's life, an operator would likely take steps to correct this condition to improve the underdriven pile capacity. An example of a corrective action is the addition of pile inserts.

6.6.3 Damaged Foundation - End-on Loading

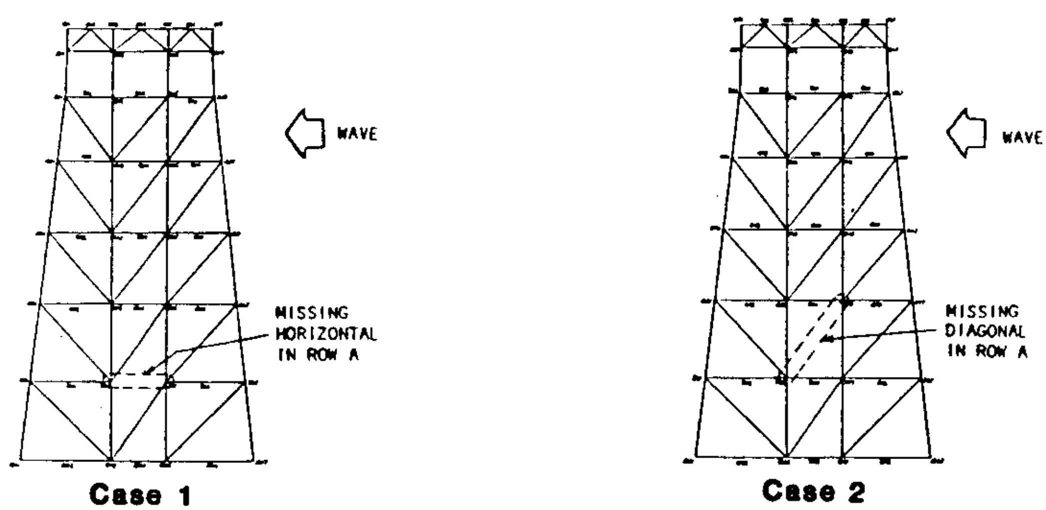
Figure 6-18 shows results of this analysis using the load profile for waves impacting the deck. The analysis was run in the weak - X-direction. The ULS capacity has been reduced by about 17 percent. The RSR for this case was in the range of 1.2 to 1.4. The greater reduction in capacity as compared to the broadside Y-direction is due to the greater contribution of the A1 piles to the platform's overturning resistance. This is caused by the location of the damaged piles far away from the pile neutral axis located midway between Rows 2 and 3.

Considering loading in this direction, it appears that the operator would have to take corrective action to repair this condition, particularly since the platform is in the early stage of its expected lifetime.

The results for both of the foundation damage cases indicated a lower reduction in ULS capacity than expected. However, this is a function of the foundation configuration and the soils at the site. Different conditions will likely generate different results.

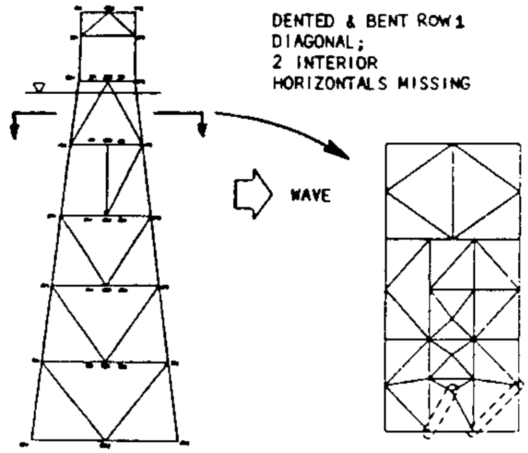


DAMAGED MEMBERS NEAR WATERLINE



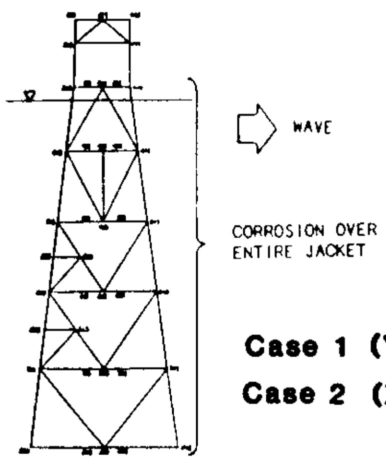
DAMAGED MEMBERS NEAR BASE OF JACKET

FIGURE 6-1 SUMMARY OF DAMAGED CASES



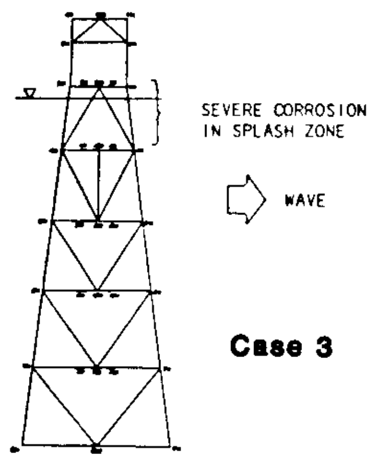
Case 1

INTERIOR HORIZONTAL DAMAGE



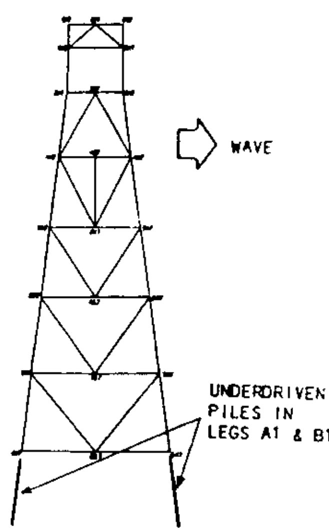
Case 1 (Y Wave)

Case 2 (X Wave)



Case 3

CORROSION DAMAGE



Case 1 (Y Wave)

Case 2 (X Wave)

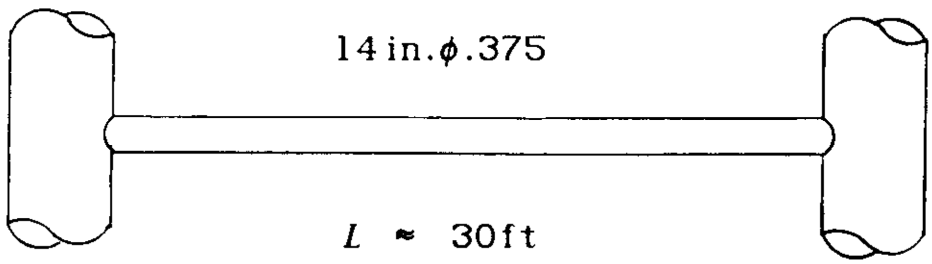
FOUNDATION DEFECTS

FIGURE 6-1 SUMMARY OF DAMAGED CASES
(Continued)

DENTED/BENT HORIZONTAL

- MODIFY CAPACITY USING "DENTA" RESULTS

- HORIZONTAL SIZE:



- EXAMPLE CAPACITY REDUCTIONS

Dent Depth (in)	Bent Offset (in)	% Full Capacity
0.5	0.5	75
3.0	0.5	37
0.5	6.0	40
3.0	6.0	20
2.0	4.0	30
2.0	3.0	35

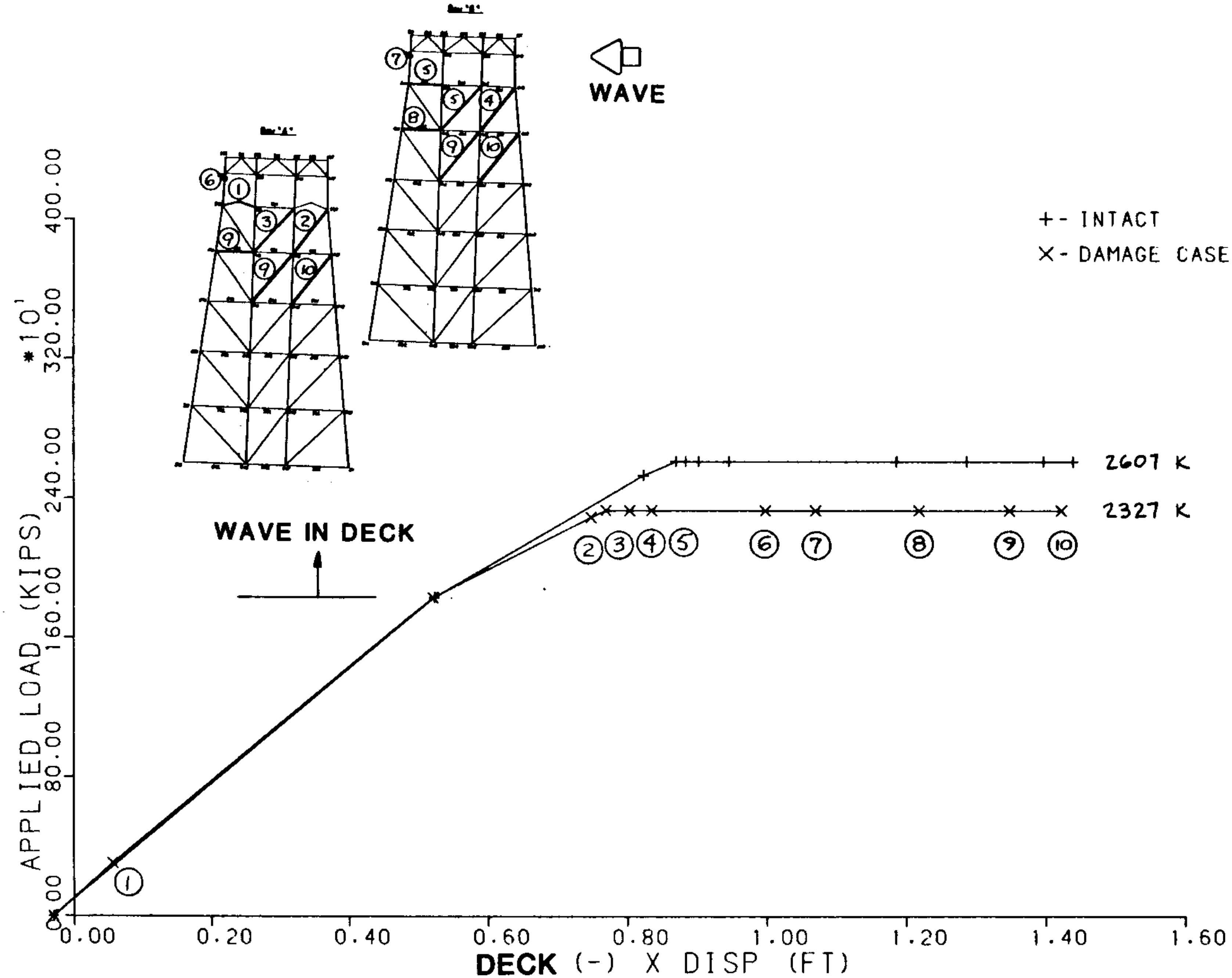
- SELECT "TYPICAL" CONDITION

  Dent Depth 2.0"

  Bent 3.0"

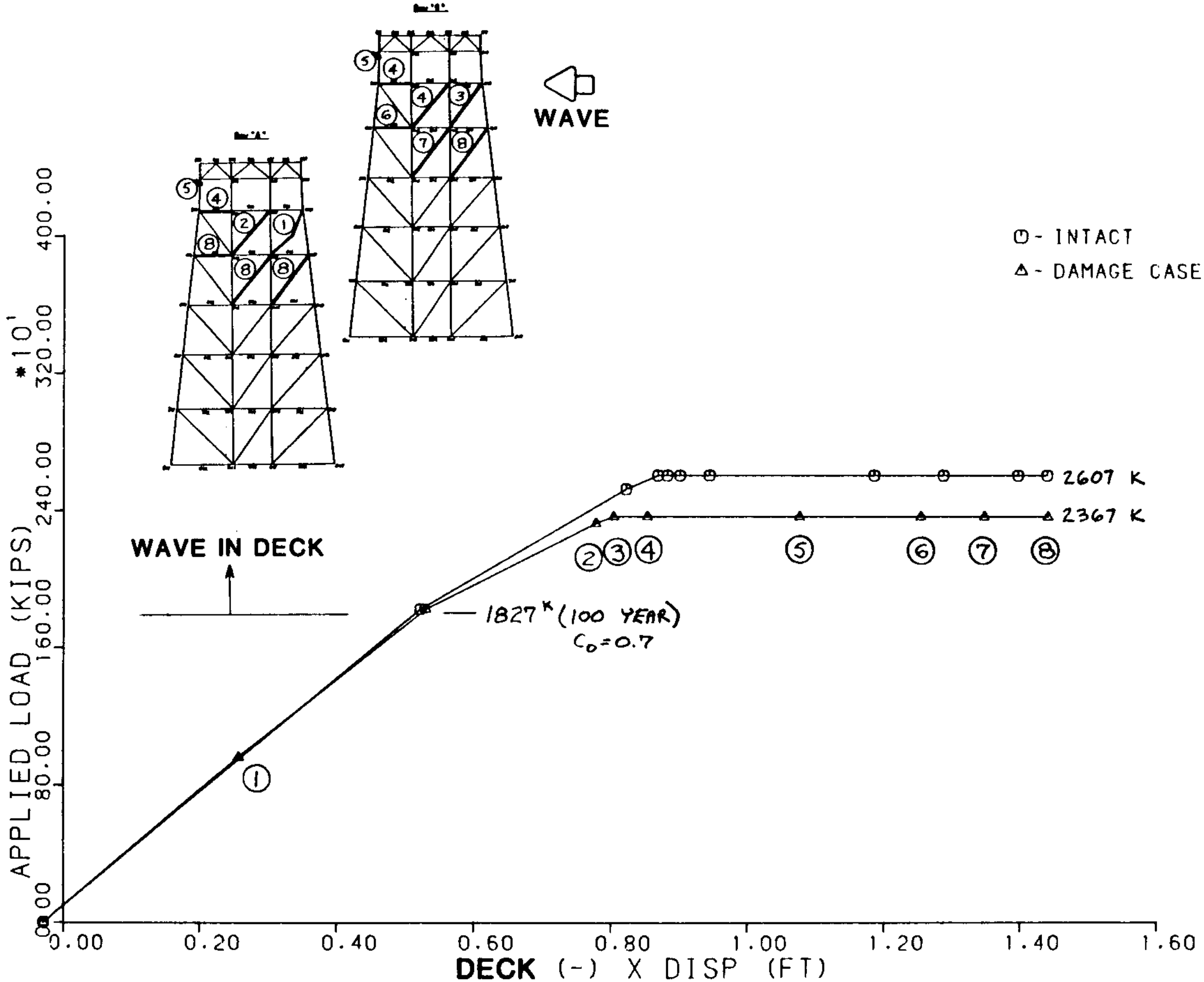
DENTA ESTIMATE OF DAMAGED HORIZONTAL BRACE CAPACITY

FIGURE 6-2



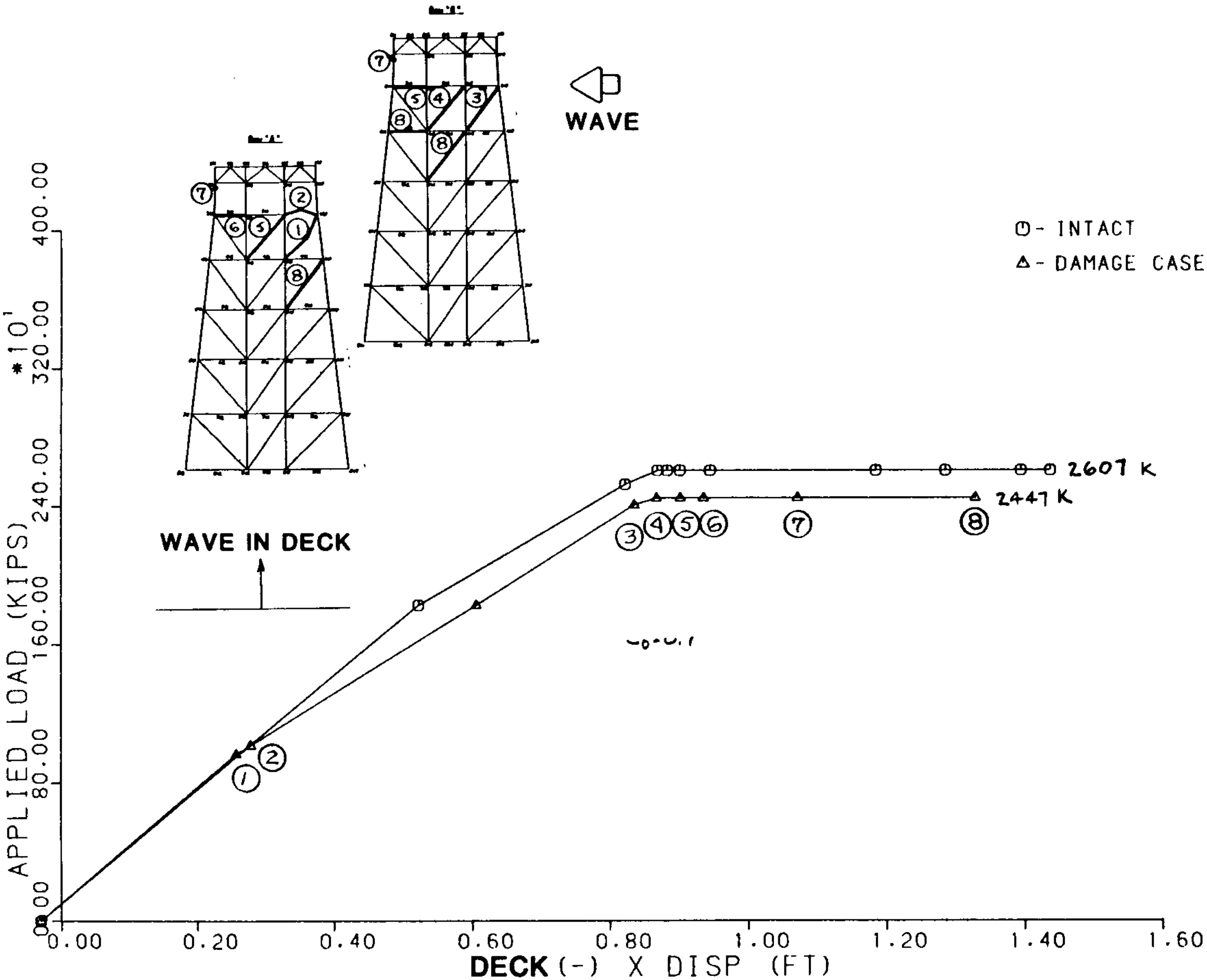
DAMAGED HORIZONTAL CONDITION

FIGURE 6-3



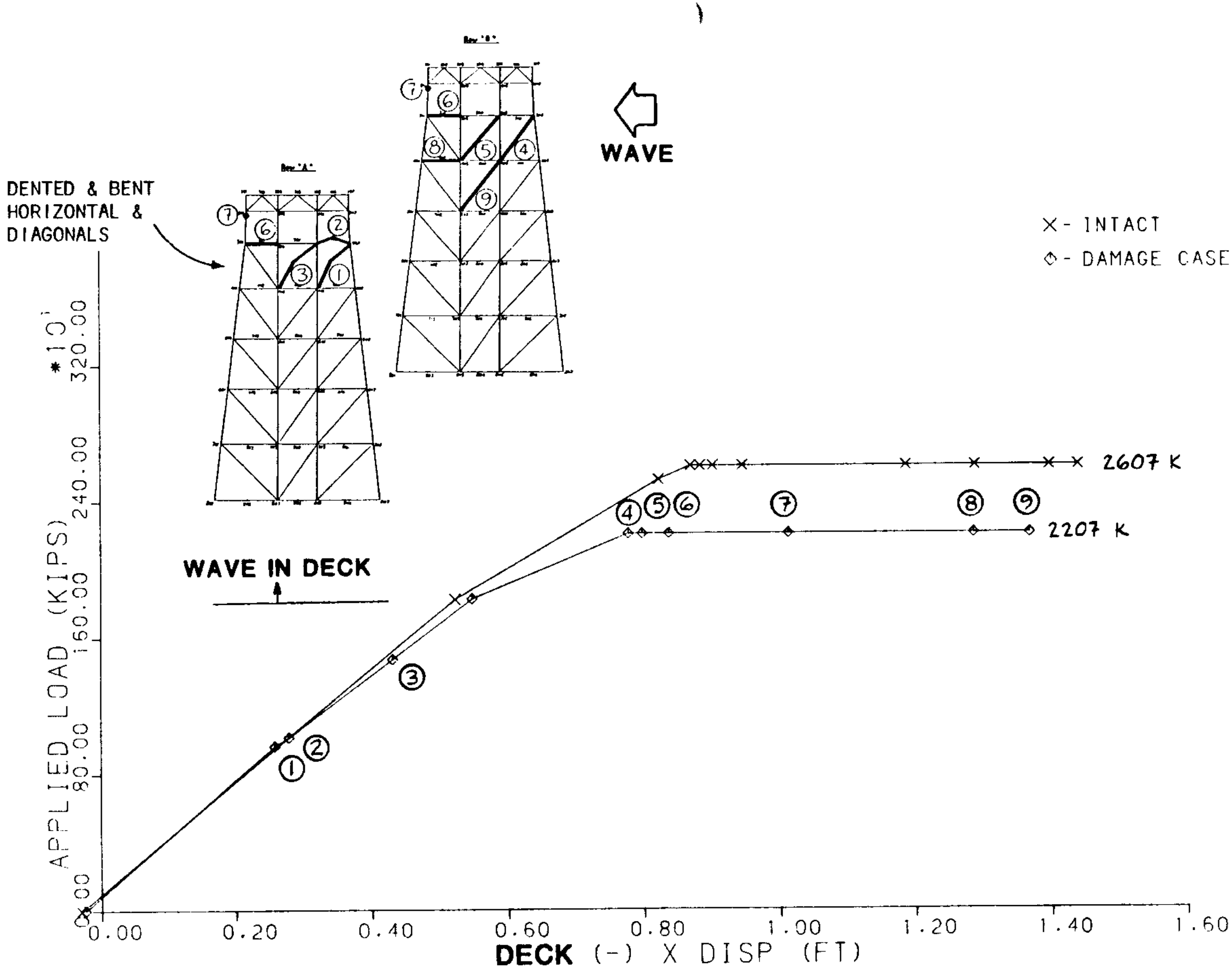
DAMAGED DIAGONAL CONDITION

FIGURE 6-4



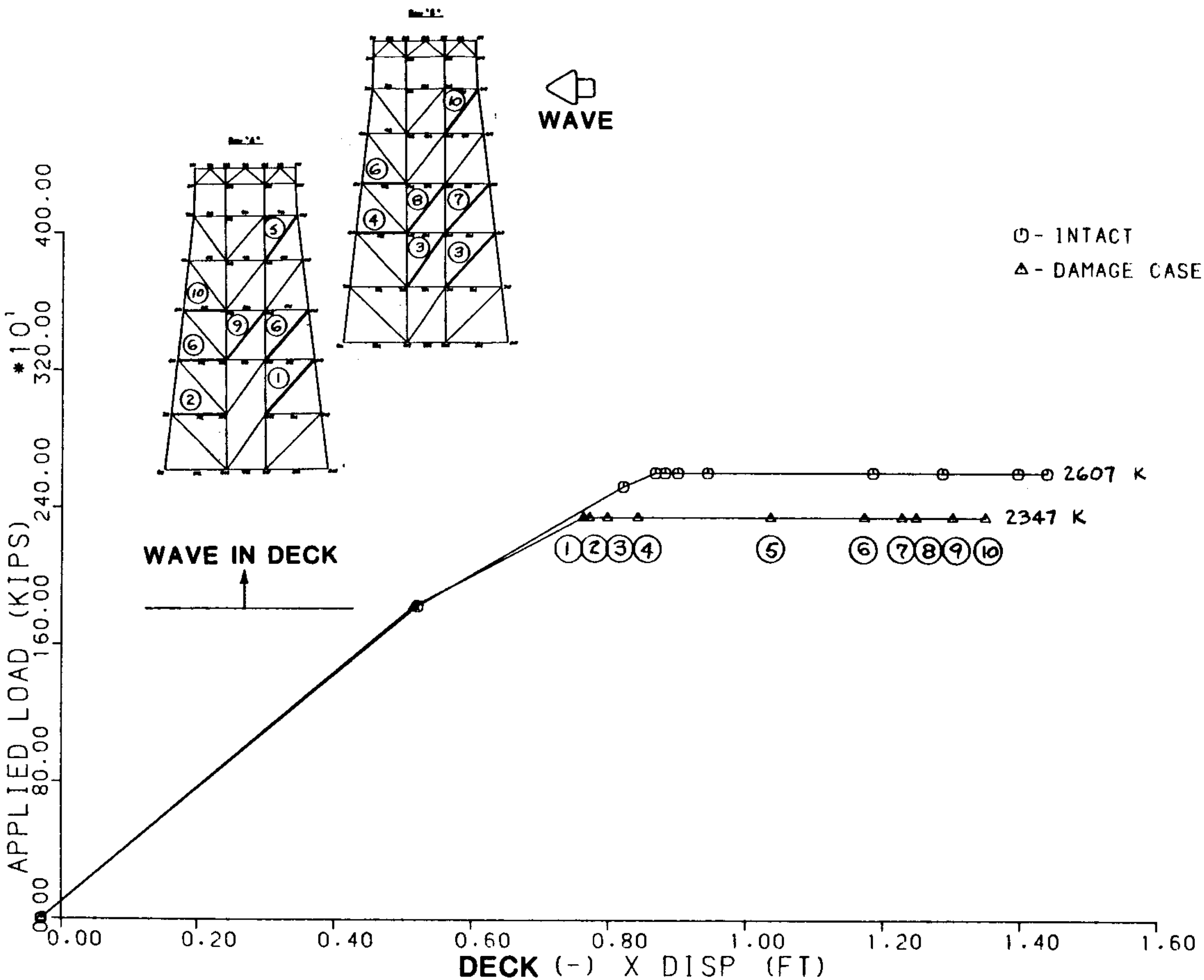
DAMAGED HORIZONTAL AND DIAGONAL CONDITION

FIGURE 6-5



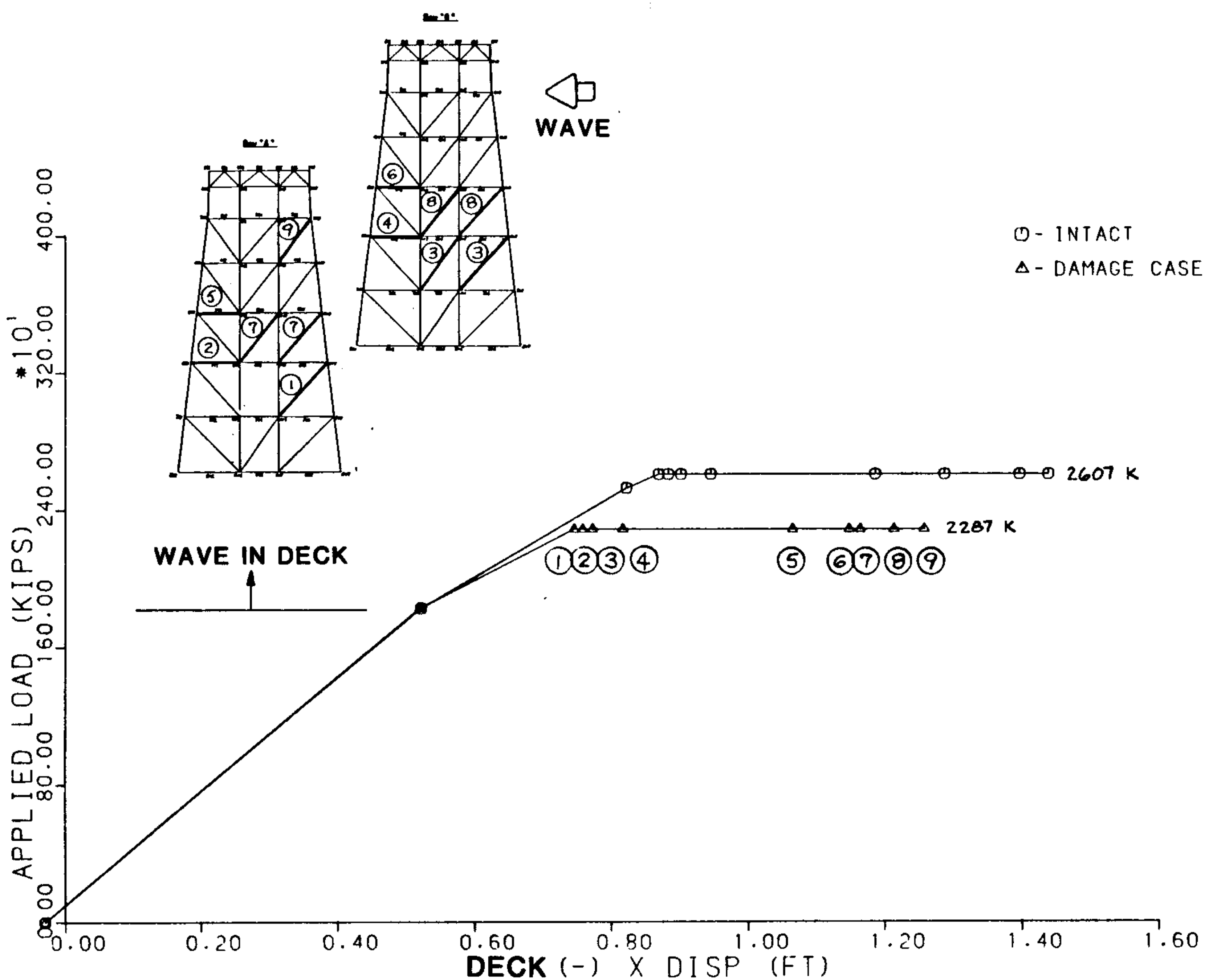
DAMAGED HORIZONTAL AND DIAGONALS CONDITION

FIGURE 6-6



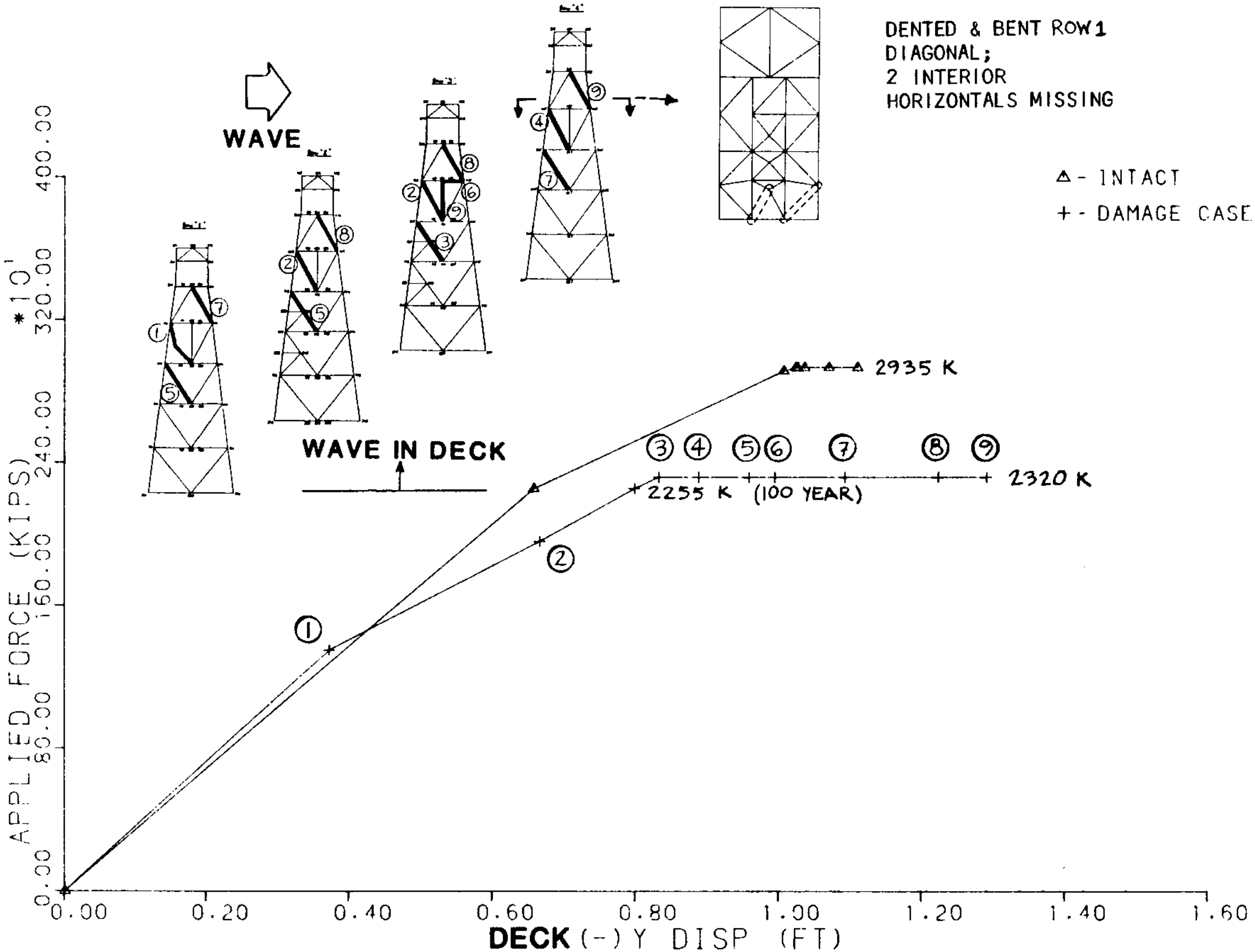
DAMAGED HORIZONTAL NEAR BASE OF JACKET

FIGURE 6-7



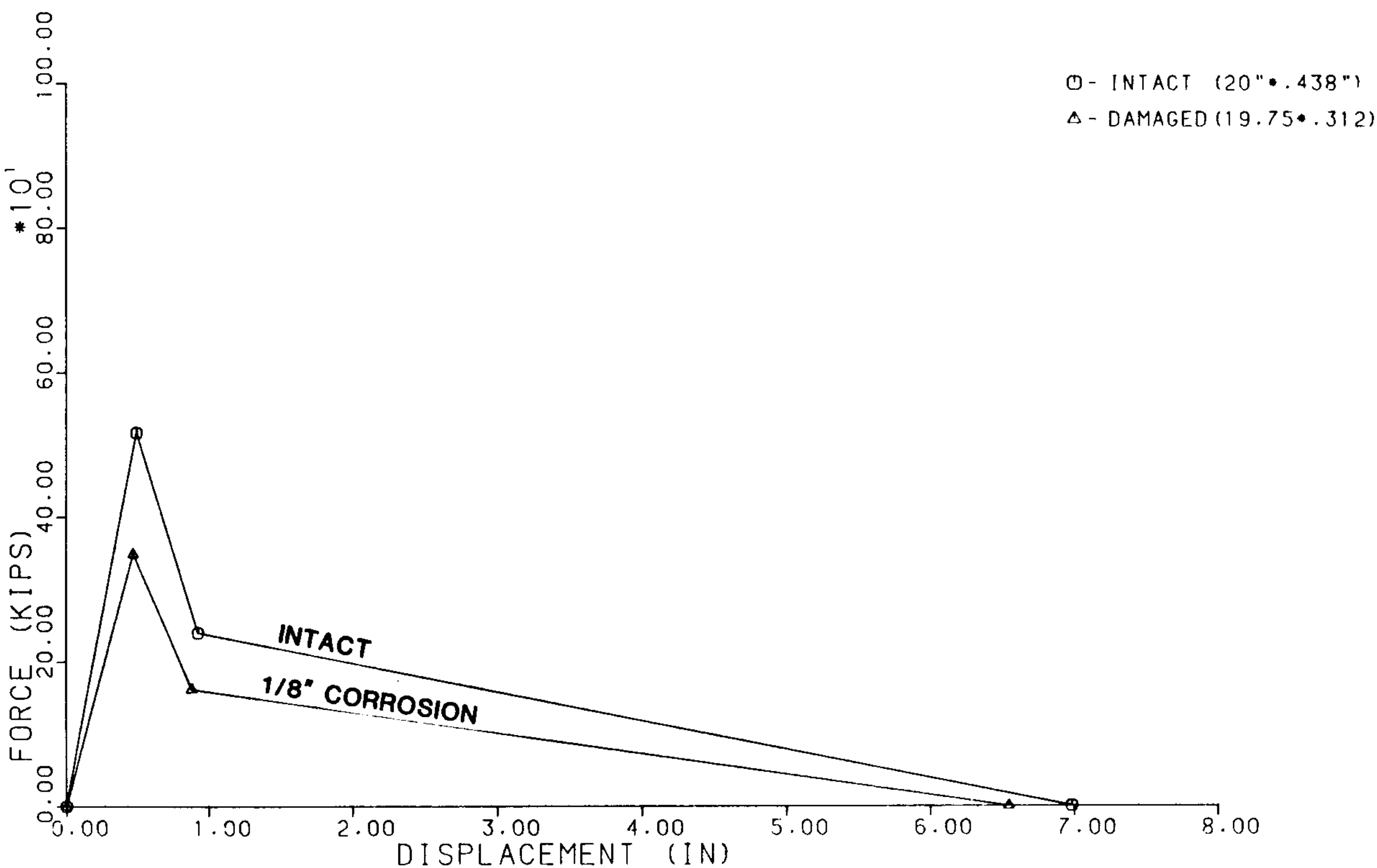
DAMAGED DIAGONAL NEAR BASE OF JACKET

FIGURE 6-8



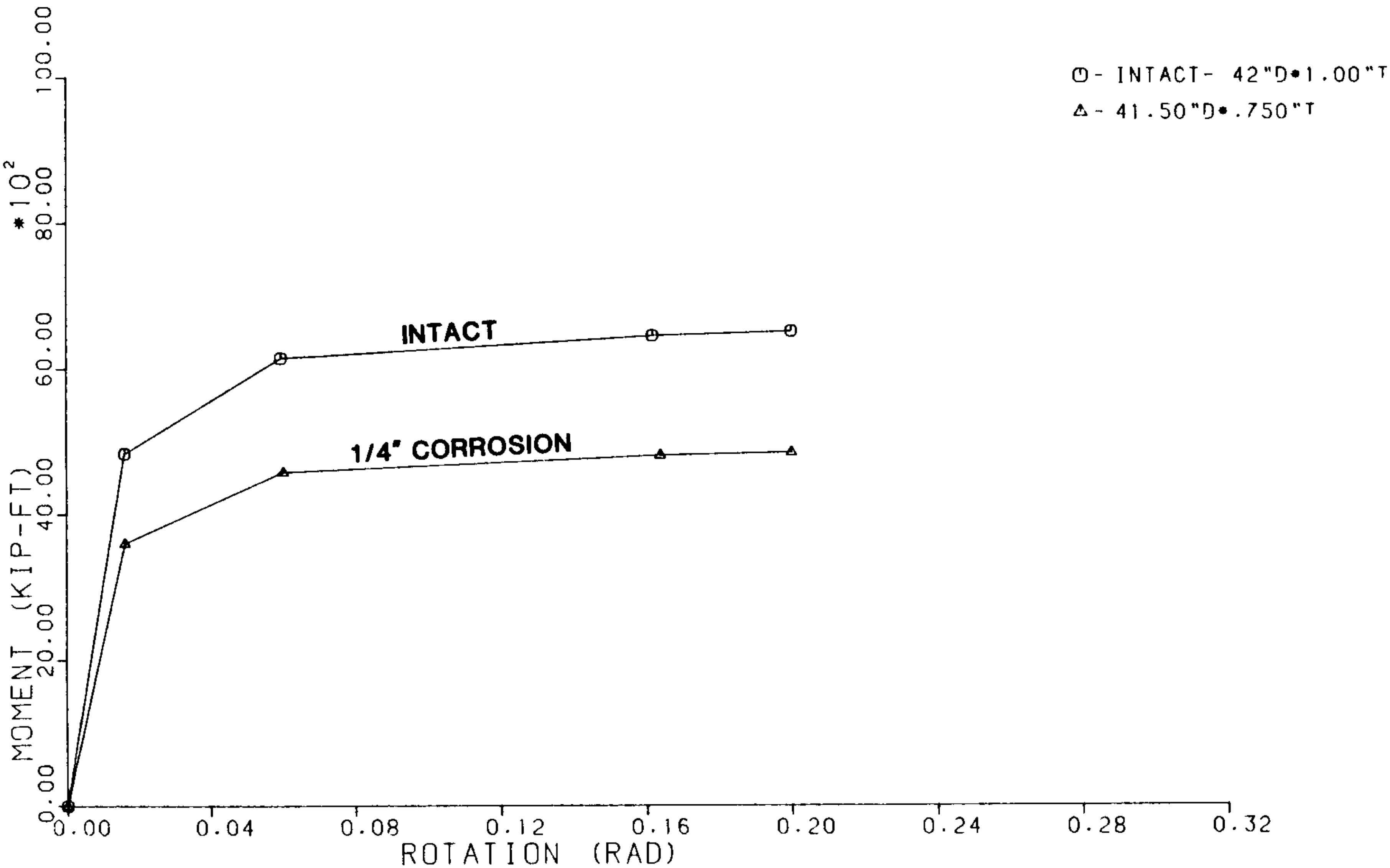
DAMAGED INTERIOR HORIZONTALS AND DIAGONAL CONDITION

FIGURE _-9



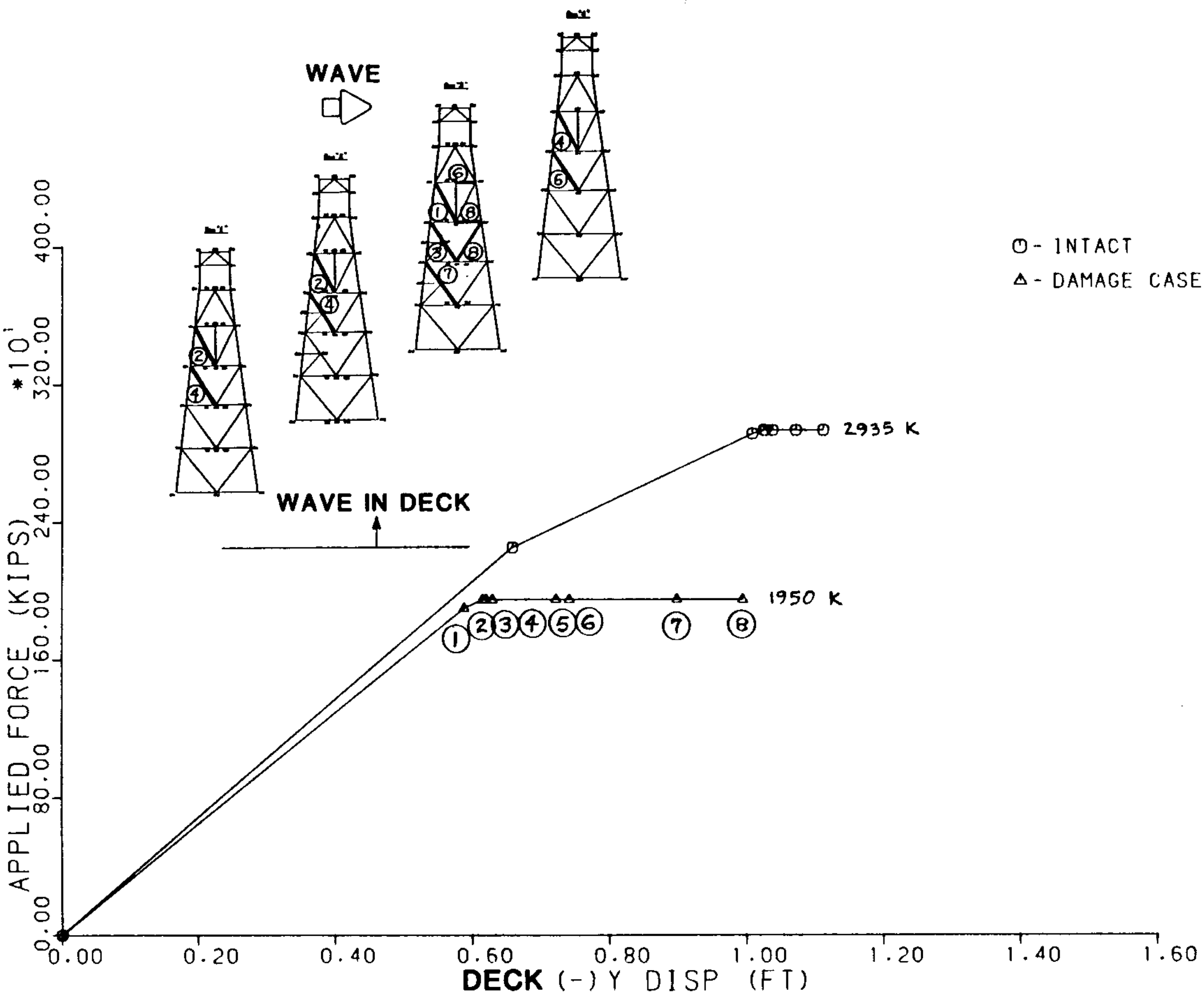
CORRODED BRACE CAPACITY

FIGURE 6-10



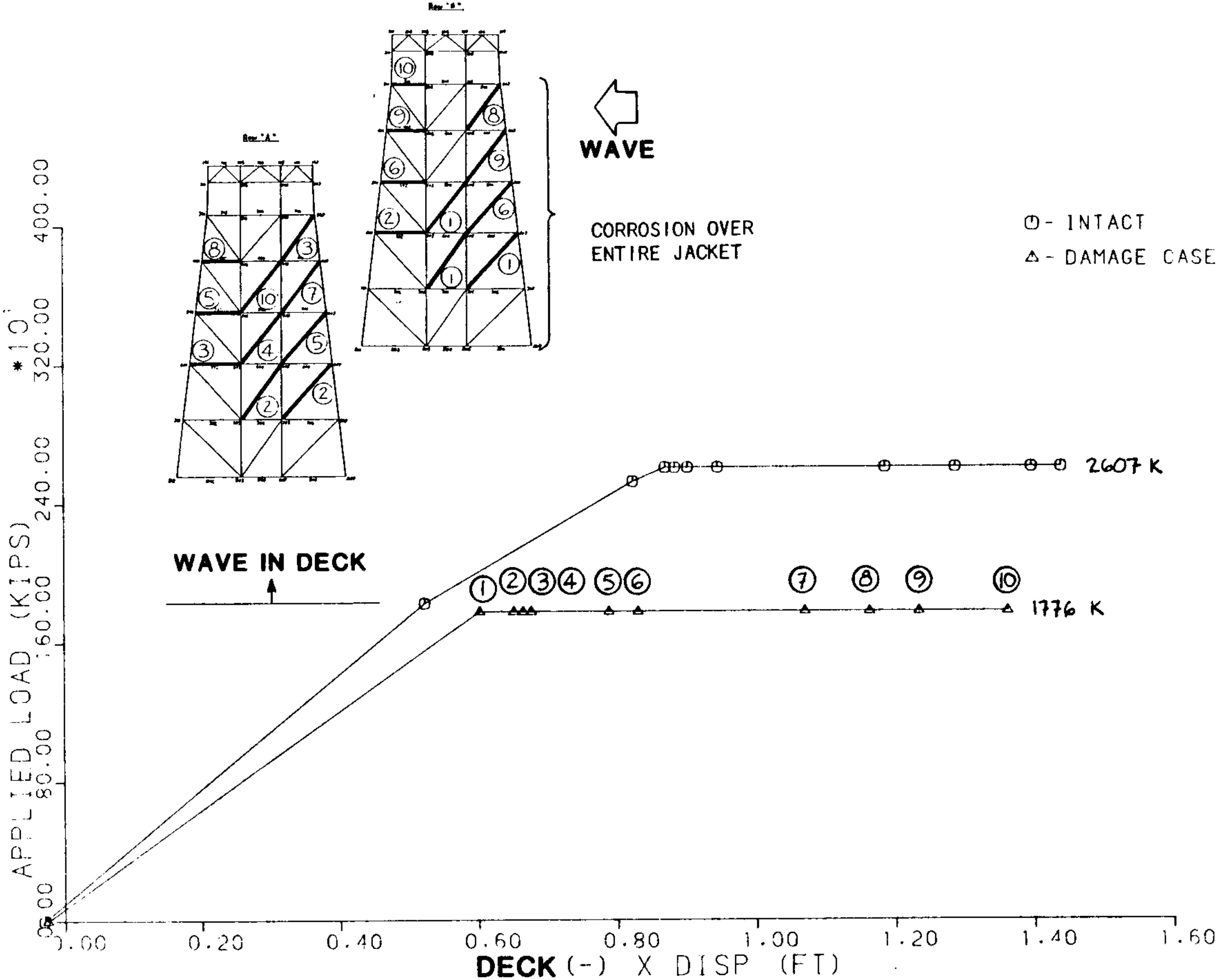
CORRODED DECK LEG CAPACITY

FIGURE 6-11



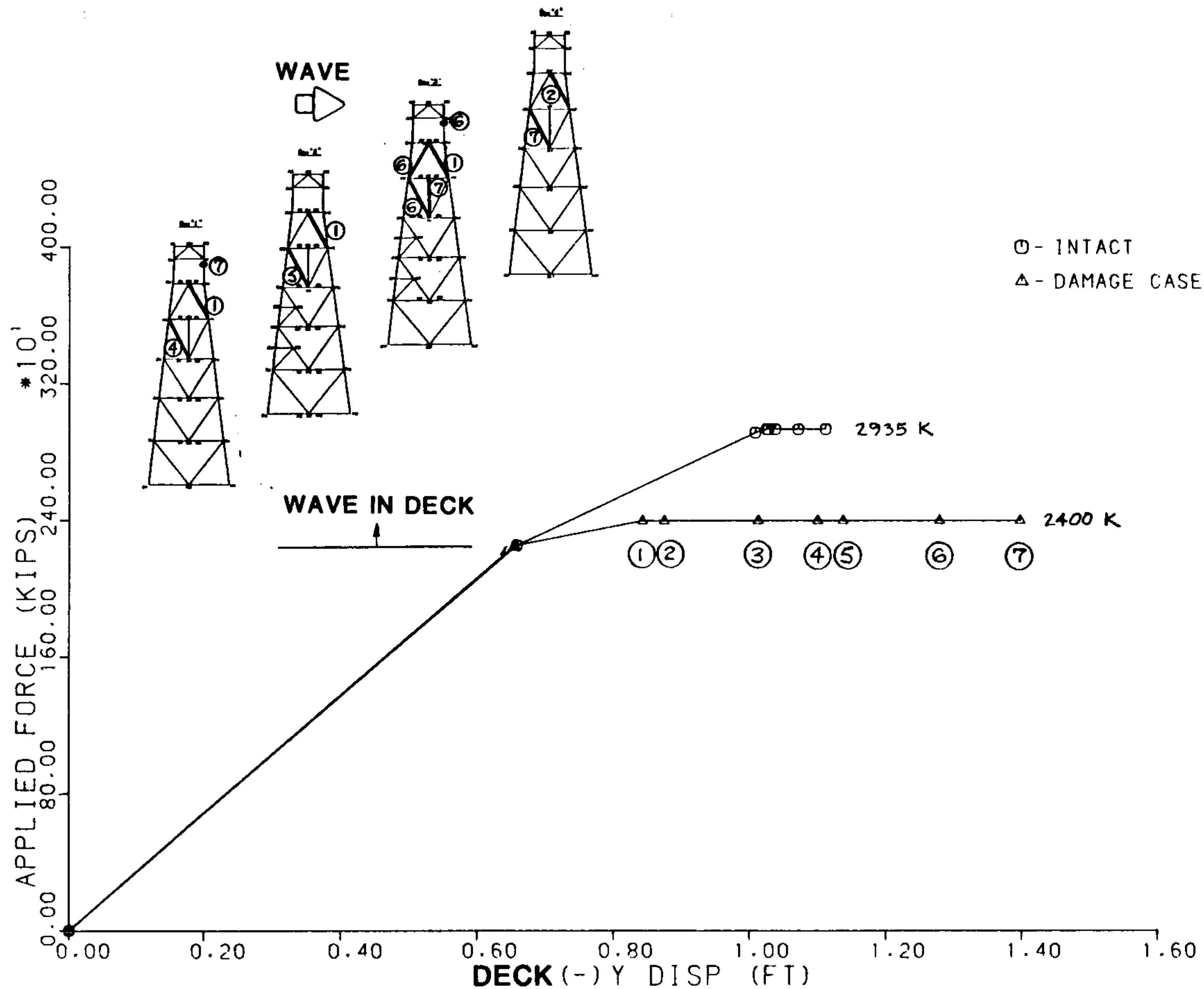
GENERAL JACKET CORROSION - BROADSIDE LOADING

FIGURE 6-12



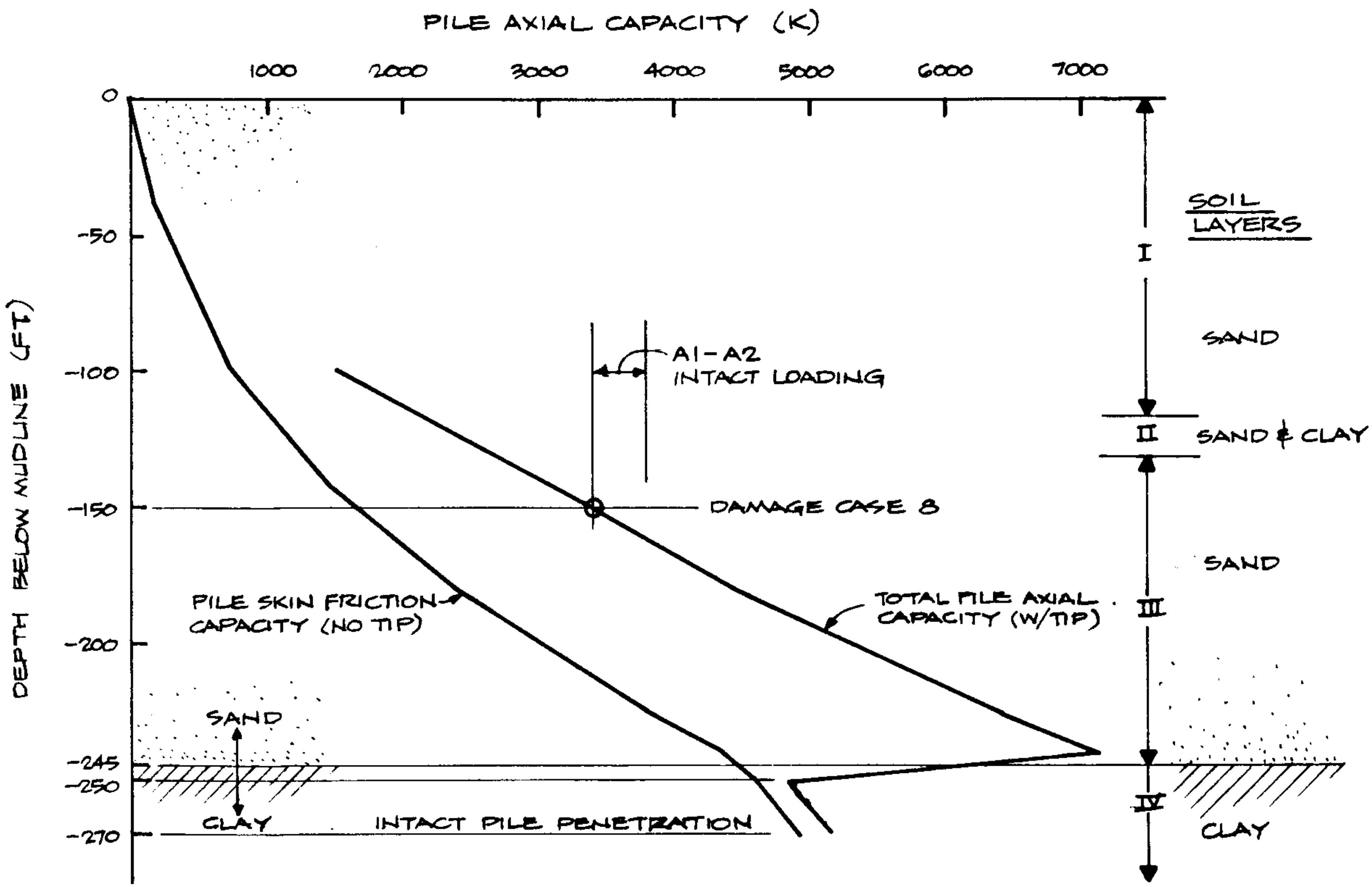
GENERAL JACKET CORROSION - END-ON LOADING

FIGURE ℓ-13



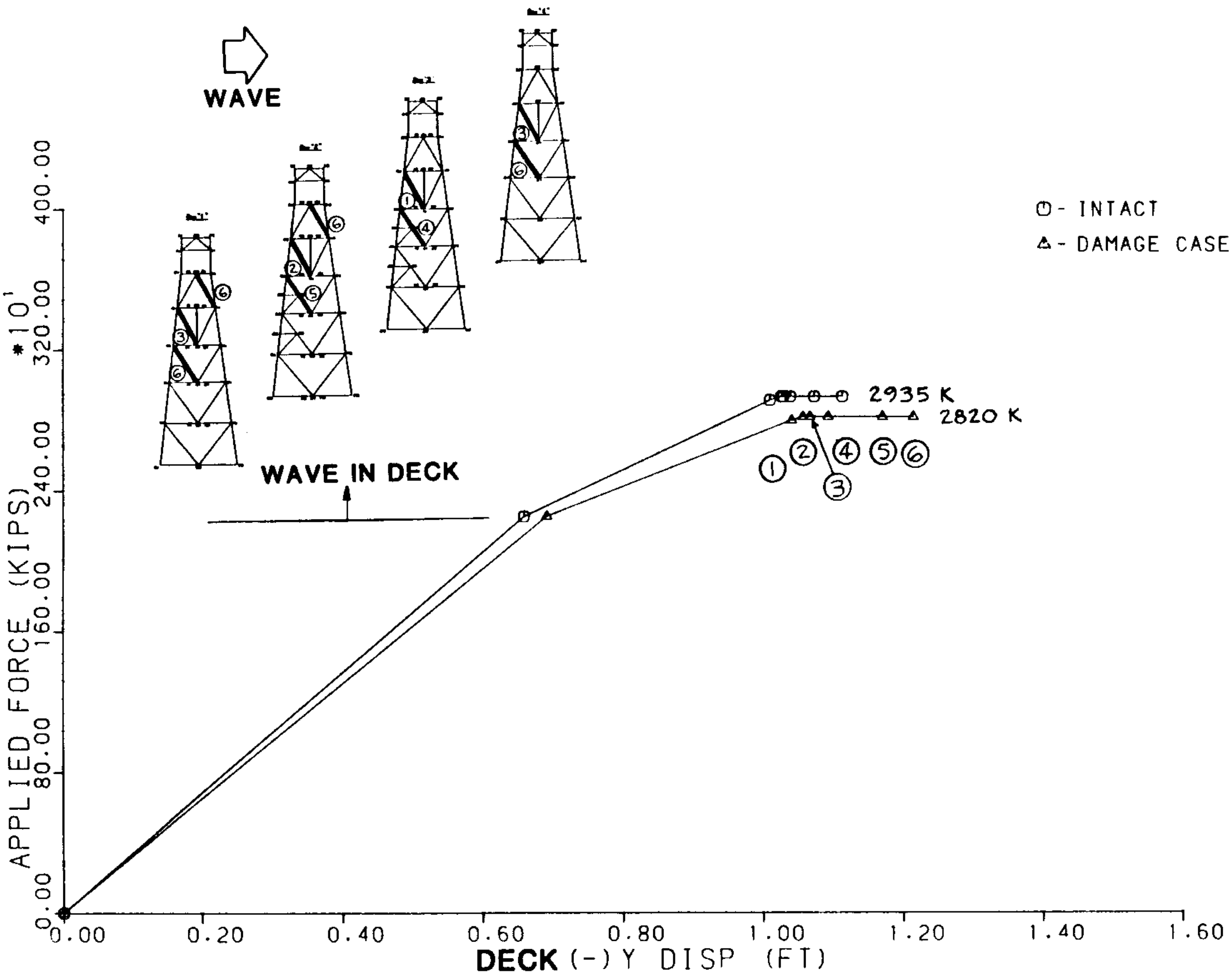
SPLASH ZONE CORROSION

FIGURE 6-14



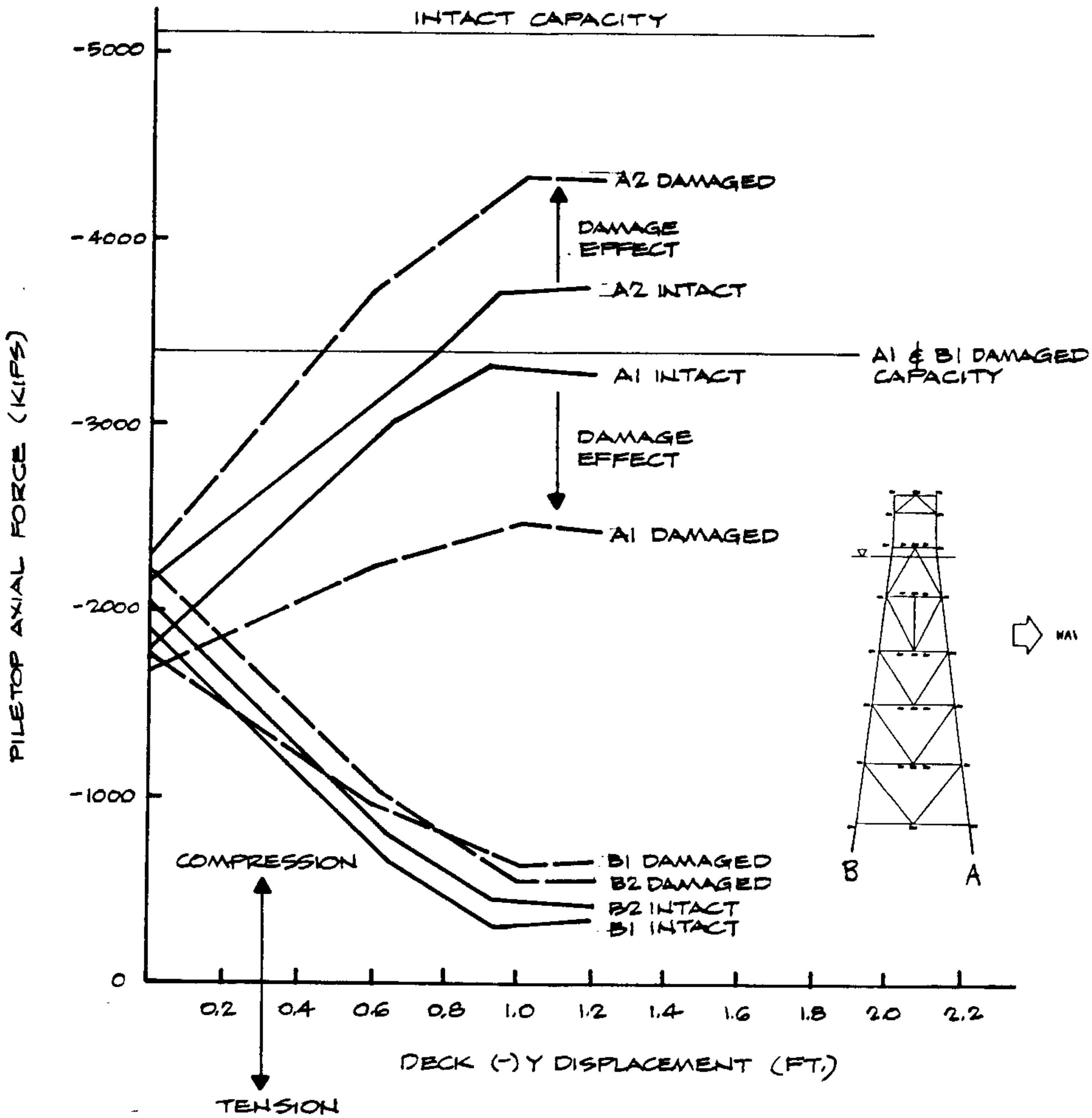
PILE CAPACITY CURVE

FIGURE 6-15



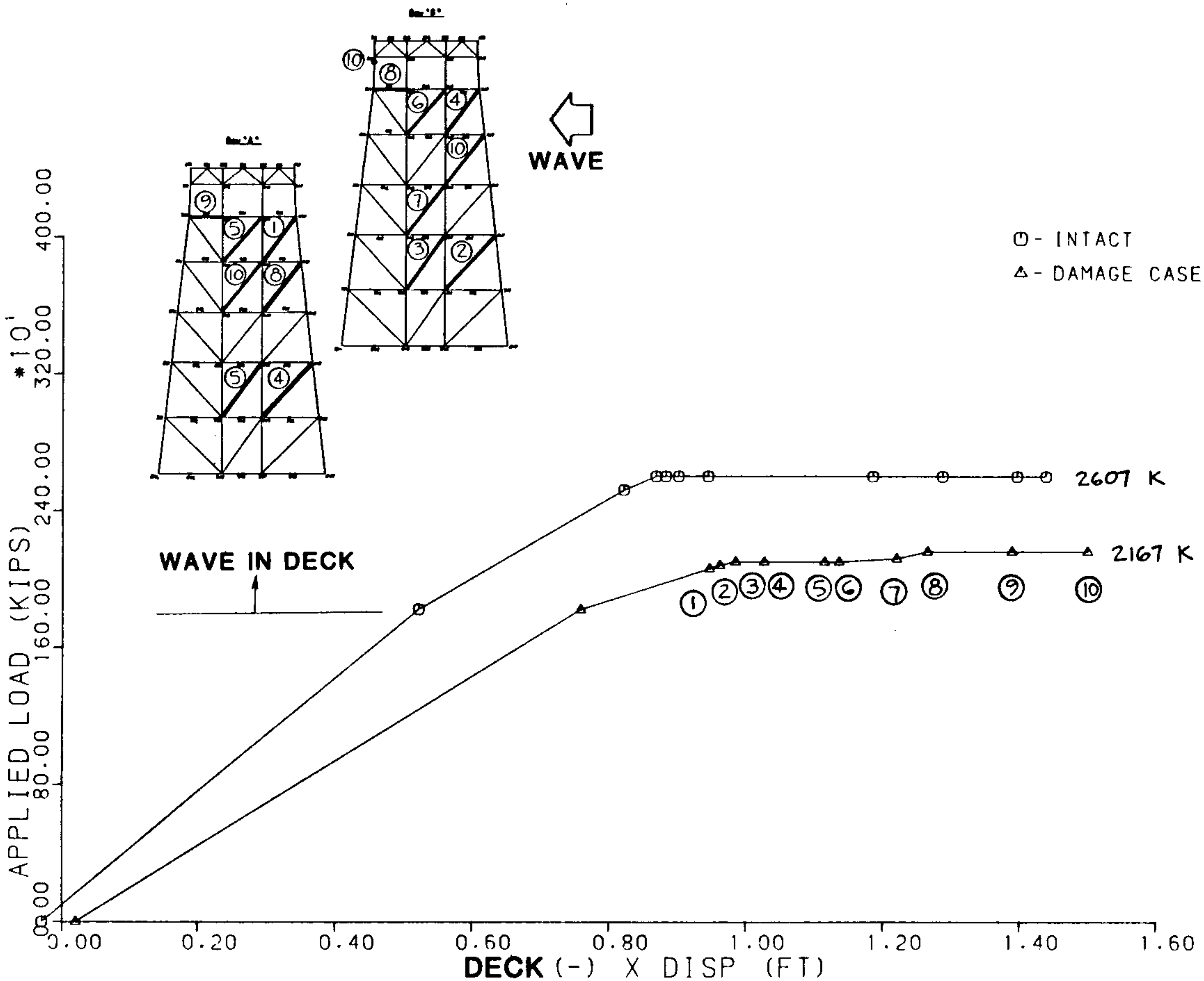
DAMAGED FOUNDATION - BROADSIDE LOADING

FIGURE 6-16



DAMAGED FOUNDATION - PILE UTILIZATION

FIGURE 6-17



DAMAGED FOUNDATION - END-ON LOADING

FIGURE 6-18

7.0 WAVE FORCES ACTING ON PLATFORM DECKS

7.1 Introduction

The objective of this section is to provide guidelines for calculating wave forces acting on the decks of platforms.

Almost without exception, failures of major drilling and production platforms in the Gulf of Mexico during hurricanes have been initiated by waves acting on platform decks. Further, these failures have been confined to platforms whose deck elevations were determined on the basis of 25-year return period wave heights and tides.

The wave force guidelines will be organized into four parts:

1. Seastate Conditions - wave heights, wave periods, storm currents, wave crest elevations.

2. Wave Kinematics - wave and current velocities in the wave crest.

3. Structure Characteristics - deck areas, shapes, spacings inundated by the wave crest.

4. Hydrodynamic Forces - horizontal and vertical forces generated by the wave crest.

The last part of this section will illustrate application of the guidelines to prediction of wave forces acting on a platform deck that failed during hurricane Hilda (1964)

7.2 Seastate Conditions

It is presumed that the seastate conditions are based on a site and platform specific oceanographic study that results in a characterization of storm wind speeds, wave heights and periods, and currents (Figure 7-1).

Storm wind speeds should be specified at the deck elevation, and be conditional on the average Return Period and time of occurrence of the expected maximum wave (Figure 7-2). The wind speeds should also be specified for the appropriate time period for determination of wind forces (e.g. 1-minute average), and in the same direction as the maximum wave (Figure 7-3).

The expected maximum wave heights and average return periods are the primary measures of storm intensities. For the purpose of computing deck hydrodynamic forces, the waves can be assumed to be close to limiting of steepness (e.g. a wave height, H, to wave length, L, ratio of 1:10).

In deep water (water depth, d, ≥ L/4), the wave length and period, T, are related by

$$L = 5.12T^2 \tag{7-1}$$

where L is in feet and T in seconds.

For H/L = 1/10,

$$T = \sqrt{2H} \tag{7-2}$$

In shallow water ($d \leq .06L$), the wave length is related to the wave period as:

$$L = 5.7T\sqrt{d} \qquad (7\text{-}3)$$

where L and d are in feet and T is in seconds. For H/L = 1/10,

$$T \cong 1.8\frac{H}{\sqrt{d}} \qquad (7\text{-}4)$$

Wave crest height above the still water level (SWL) can be determined empirically [22,23] or from appropriate high order wave theories [24,25,26]. In deep water, and for waves close to limiting steepness (H/L = 1/7 to 1/10), the ratio of crest height, η_c, to wave height, ϵ, is approximately [22,23]:

$$\epsilon = \frac{\eta_c}{H} = 0.55 \text{ to } 0.6 \qquad (7\text{-}5)$$

The wave crest elevations will be the sum of the storm tide and crest height.

7.3 Wave Kinematics

Wave kinematics should be based on an appropriate wave theory for the wave heights, periods, degree of directional spreading, and water depths of interest [4].

In deep water, the maximum horizontal velocity at the wave crest and the vertical velocity at the quarter points before (up) and after (down) the wave crest can be approximated as (Figure 7-4):

$$V_H = V_V = \frac{\pi H}{T} \qquad (7\text{-}6)$$

Recalling the relationship between wave height and period for a height-to-length ratio of 1:10:

$$V_H = V_V \cong 2.2\sqrt{H} \quad \text{(ft, sec)} \qquad (7\text{-}7)$$

In shallow water ($d \leq .06L$), the horizontal particle velocity at the wave crest can be estimated as:

$$V_H = \frac{\pi H}{T\left(\frac{2\pi d}{L}\right)} \qquad (7\text{-}8)$$

or,

$$V_H = 2.8\frac{H}{\sqrt{d}} \quad \text{(ft, sec)} \qquad (7\text{-}9)$$

The horizontal wave crest velocities should be added vectorially to the surface current velocities. It will be the component of the current velocity in the direction of the wave velocity, V_{CW}, that will be important in determining deck hydrodynamic forces:

$$V_{WCH} = V_H + V_{CW} \qquad (7-10)$$

7.4 Structure Characteristics

As a wave crest passes through a platform deck, the water encounters a wide variety of structural shapes, mechanical equipment, and production facilities (Figure 7-5) [7].

The water runs up the faces of the obstructions it encounters (like a bow wave) and is drawn down behind the obstruction (Figure 7-6). The run-up and draw-down dimensions, Δ, are approximately one velocity head [22]:

$$\Delta = \frac{V_H^2}{2g} \tag{7-11}$$

The obstruction shapes, spacings, and "roughness" will influence the hydrodynamic forces and force coefficients (Figures 7-7, 7-8, 7-9).

In computing deck wave forces, it will be useful to estimate the area projected to the wave crest, A_p, as the product of the deck width, W, and the crest height acting on the deck, h_c (Figure 7-6):

$$A_{ph} = W \times h_c \tag{7-12}$$

Similarly, it will be useful to estimate an overall shape, spacing, and roughness for the particular deck structure, equipment and drilling-production facilities. This approach is similar to the "blockage" and drag coefficients used in estimating wind forces acting on platform decks [6,11].

7.5 Hydrodynamic Forces

The maximum hydrodynamic force, F_H, acting on platform decks will be estimated using a total force coefficient, C_T, as follows [28]:

$$F_H = \frac{1}{2}\rho C_T A_{ph} V_H^2 \qquad (7\text{-}13)$$

The total force coefficient for widely spaced smooth cylinders can be determined as follows (Figure 7-7):

$$C_T = \frac{2\pi^2}{K} \quad \text{(small K)} \qquad (7\text{-}14)$$

$$C_T = C_{TS} \quad \text{(large K)} \qquad (7\text{-}15)$$

The turbulence of the water flow is reflected in the Keulegan-Carpenter Number, K, as:

$$K = \frac{V_H T}{D} \qquad (7\text{-}16)$$

where D is the member diameter, T the wave period, and V_H the water particle maximum horizontal velocity.

The steady flow (high K's) coefficient, C_{TS}, for smooth, widely spaced cylinders, is about 0.6, and for rough cylinders is about 1.1.

The effects of other shapes (e.g. flat plates, angles, wide-flanges) would be to increase the steady flow coefficients to the order of 1.5 to 2 (Figure 7-8) [11].

Shielding will act to reduce the forces that would be presumed based on treating all of the obstructions as widely spaced (Figure 7-9). Also, the geometry of the wave crest relative to the deck may be such that the entire deck is not inundated (Figure 7-10).

Due to flow effects developed near the wave free surface (Figure 7-6), there is an effective reduction in the force coefficients in this part of the wave [11,27,30]. The reduction in the total force coefficient is principally in the upper two velocity heads (2 Δ) of the wave crest. The coefficient is zero at the free surface and increases approximately linearly to its normal value at depths remote from the free surface at a depth of two velocity heads.

For example, in deep water a wave height of 64 feet near limiting steepness could be estimated to have a maximum horizontal water particle velocity of:

$$V_H = 2.2\sqrt{H} = 17.6\,\mathrm{ft/sec} \tag{7-17}$$

This velocity might be added to a storm current velocity of 4 ft/sec to give a resultant velocity of 21.6 ft/sec. Thus,

$$\begin{aligned} 2\Delta &= \frac{2\cdot(21.6\,\mathrm{ft/sec})^2}{2\cdot 32.2\,\mathrm{ft/sec}^2} \\ &= 14.4\,\mathrm{ft} \end{aligned} \tag{7-18}$$

Given $C_{TS} = 2$, the average total force coefficient in the upper 14.4 feet of wave crest would be $C_{TS} = 1$.

7.6 Example and Calibration

To illustrate application of the foregoing guidelines, an example 8-leg platform deck inundated by waves in hurricane Hilda will be studied (Figure 7-12) [31]. Because this platform deck failed during the hurricane (Figure 7-13), the example also will provide an interesting calibration of the guidelines.

The example 8-leg drilling and production platform is a "standard" (for its time, 1962) "25-year" wave design [31]. The platform is located in a water depth of 172 feet in the central Gulf of Mexico. The platform supports three wells.

Figure 7-14 shows some details of the platform's deck. The platform supports three wells. The main deck (116 ft by 66 ft) is located 48 feet above mean Gulf level (MGL). The cellar deck (60 ft by 40 ft) is located 32 feet above MGL. The platform is oriented with its long axis in a northeast-southwest direction.

The platform has a minimum self-contained drilling rig with a full load of pipe, fuel, mud and supplies. The total weight of the drilling-production unit is between 2000 and 3000 tons (2500 tons will be assumed). The weight of the deck is approximately 300 tons. The deck is supported by eight 36-inch diameter, 0.625-inch wall thickness legs that join the piles at the top of the jacket 24 feet below the lower deck chord.

The dimensions of the upper deck equipment are summarized in Table 7-1.

The platform was about 15 miles east of the path of hurricane Hilda (1964). The platform had been in place less than one year.

Based on damage observations and wave staff recordings from nearby platforms [7,32], the maximum wave height was estimated to have been 64 feet. The storm surge was estimated to be 2 feet. The hurricane surface current component in the direction of the maximum waves (from southeast) was estimated to be 3 feet per second.

For a maximum wave height of 64 feet, the wave crest height would be about 45 feet ($\eta_c = 0.7$ H) [22,23]. A storm time at the time of the maximum surge of 2 feet would indicate a wave crest elevation of +47 feet MGL (Figure 7-15).

With the bottom of the main platform deck located at +46 feet MGL, it would have been one foot into the maximum wave crest, and subjected to the wave run-up (Figure 7-6). It would also be subjected to the hurricane winds. The wind speed (1 minute average) was estimated to be 150 miles per hour at the time of the maximum wave.

The lower cellar deck (grated) located at +32 feet would have been completely inundated by the wave crest. With the maximum wave principal direction from the southeast, the platform would have been subjected to a broadside wave attack. Due to the grating, the vertical wave forces would be expected to be relatively small.

The lower deck width was 60 feet. The projected (shadow) area of the lower deck, well-heads, conductors, equipment and facilities is 500 square feet (Figure 7-15).

The main deck width was 116 feet. As discussed later, the deck facilities height subject to wave run-up would have been about 7.6 feet. Thus, the projected area would be about 700 square feet (Figure 7-15).

The composite shape, roughness, and spacing characteristics of the lower deck indicate a $C_{TS} = 2$.

Given a maximum wave height of 64 feet and a near limiting steepness of H/L = 1/10, the wave length would be 640 feet. Given a storm water depth of 174 feet, the wave would be a deep water wave.

The wave period would be:

$$T = \sqrt{2H} \tag{7-19}$$

$$T = 11.3 \text{ sec}$$

The maximum horizontal velocity in the wave crest would be:

$$V_H = \frac{\pi H}{T} = \pi \frac{64}{11.3} = 17.7 \text{ ft/sec} \tag{7-20}$$

Adding 3 fps surface current would result in V_{HT} = 20.7 fps.

The run up would be:

$$\Delta = \frac{V^2}{2g} = \frac{20.7^2}{2(32.2)} = 6.6 \text{ ft}$$

which would mean an inundation of the upper deck of 1 + 6.6 = 7.6 ft, since the wave crest is 1 ft above the bottom of the deck.

The two velocity head depth below the wave crest runup would be:

$$2\Delta = \frac{V^2}{g} = \frac{\left(20.7\frac{f}{s}\right)^2}{32.2\frac{f}{s^2}} = 13.2 \text{ ft} \tag{7-21}$$

The turbulence parameter would be:

$$K = \frac{VT}{D} = \frac{\left(20.7\frac{f}{s}\right)(11.3s)}{(1\,ft\ to 3\,ft)} \qquad (7\text{-}22)$$

$$K = 78 \text{ to } 233$$

Presume $C_T = C_{TS}$ (Figure 7-7).

The average C_T in the top 13.2 feet of crest and run-up would be 1.0. The average C_T in the next 8.4 feet of crest acting on the deck would be 2.0.

The upper deck area $C_T = 1.0$, and the lower deck area $C_T = 2.0$.

Given an effective projected area of 500 square feet on the lower deck, the total lateral deck wave force would be:

$$F_{TH} = \frac{1}{2}\rho C_T \cdot A_{ph} \cdot V_H^2 \qquad (7\text{-}23)$$

$$F_{TH} = \frac{1}{2}\left(\frac{.064}{32.3}\right)2 \times 500\,ft^2 \cdot \left(20.7\frac{f}{s}\right)^2$$

$$T_{TH} = 428 \text{ kips} \qquad \text{(Figure 7-16)}$$

Given an effective projected area of 700 square feet on the upper deck, the total lateral deck wave force would be:

$$F_{TH} = \frac{1}{2}\left(\frac{.064}{32.2}\right) \times 1 \times 700\,ft^2 \cdot \left(20.7\frac{f}{s}\right)^2 \qquad (7\text{-}24)$$

$$F_{TH} = 300 \text{ kips}$$

The wave force acting directly on the eight 36-inch diameter legs and three 26-inch diameter conductors would be:

$$F_{TH} = \frac{1}{2}\left(\frac{.064}{32.2}\right)(8 \times 3\,\text{ft} + 3 \times 2.2\,\text{ft})(24\,\text{ft})(0.6)\left(20.7\frac{f}{s}\right)^2$$

$$F_{TH} = 189 \text{ kips} \tag{7-25}$$

The total lateral wind force acting on the exposed facilities on the upper deck (Table 7-1) could be estimated as follows:

1. Project Blockage Area = 1800 ft^2

2. Wind Force Coefficient = 2

3. Wind Velocity = 150 mi/hr = 220 ft/sec

4. F_{WH} = 0.0012 x 2 x 1800 ft^2 x $(220\ f/s)^2$

   F_{WH} = 209 kips (Figure 7-16)

The total overturning moment, M_T, generated by this force system at the top of the jacket would be (Figure 7-16):

$$M_T = 33{,}500 \text{ k ft}$$

or per leg:

$$M = 4{,}190 \text{ k ft}$$

The total lateral hydrodynamic force acting on the deck would be about 917 kips.

The maximum and minimum deck leg axial loads would be about 870 kips and 450 kips, respectively.

The deck leg structural properties are as follows:

1. $D = 36$ inches

2. $t = 0.625$ inch

3. $A = 70\ in^2$ (Section Area)

4. $Z = 604\ in^3$ (Elastic Section Modulus)

5. $Z_p = 773\ in^3$ (Plastic Section Modulus)

6. $f_{YN} = 36$ ksi (Nominal Yield Stress)

7. $f_U = 45$ ksi (Average Ultimate Strength)

Given a leg axial force of 450 kips to 870 kips and leg moments of 4,190 ft-kips, the maximum combined stresses would be:

$$f_U = \frac{450 \text{ to } 870 \text{ k}}{70 \text{ in}^2} + \frac{4{,}190 \text{ k ft} \cdot 12\frac{\text{in}}{\text{ft}}}{773 \text{ in}^3} \qquad (7\text{-}26)$$

$$f_U = 6 \text{ to } 12 \text{ ksi} + 65 \text{ ksi}$$

$$f_U = 71 \text{ to } 77 \text{ ksi} > 45 \text{ ksi}$$

Given an average ultimate strength of 45 ksi, it is not surprising that the deck failed at the top of the jacket (Figure 7-13).

7.7 Summary

This section has summarized a guideline for evaluation of wave forces acting on platform decks. The guideline addresses:

1. Seastate Conditions
2. Wave Kinematics
3. Structure Characteristics
4. Hydrodynamic Forces

The hydrodynamic forces, F_H, are evaluated from equation 7-13:

$$F_H = \frac{1}{2}\rho C_T \cdot A_{ph} \cdot V^2$$

The total force coefficient, C_T, is based on the proximity of the structure to the free surface, turbulence, roughnesses, shapes, and spacings.

The effective projected area of the structure, A_{ph}, depends on the wave crest elevation, the geometry of the wave and structure, wave run up and drawn down, and the dimensions of structural shapes, equipment and facilities inundated by the wave action.

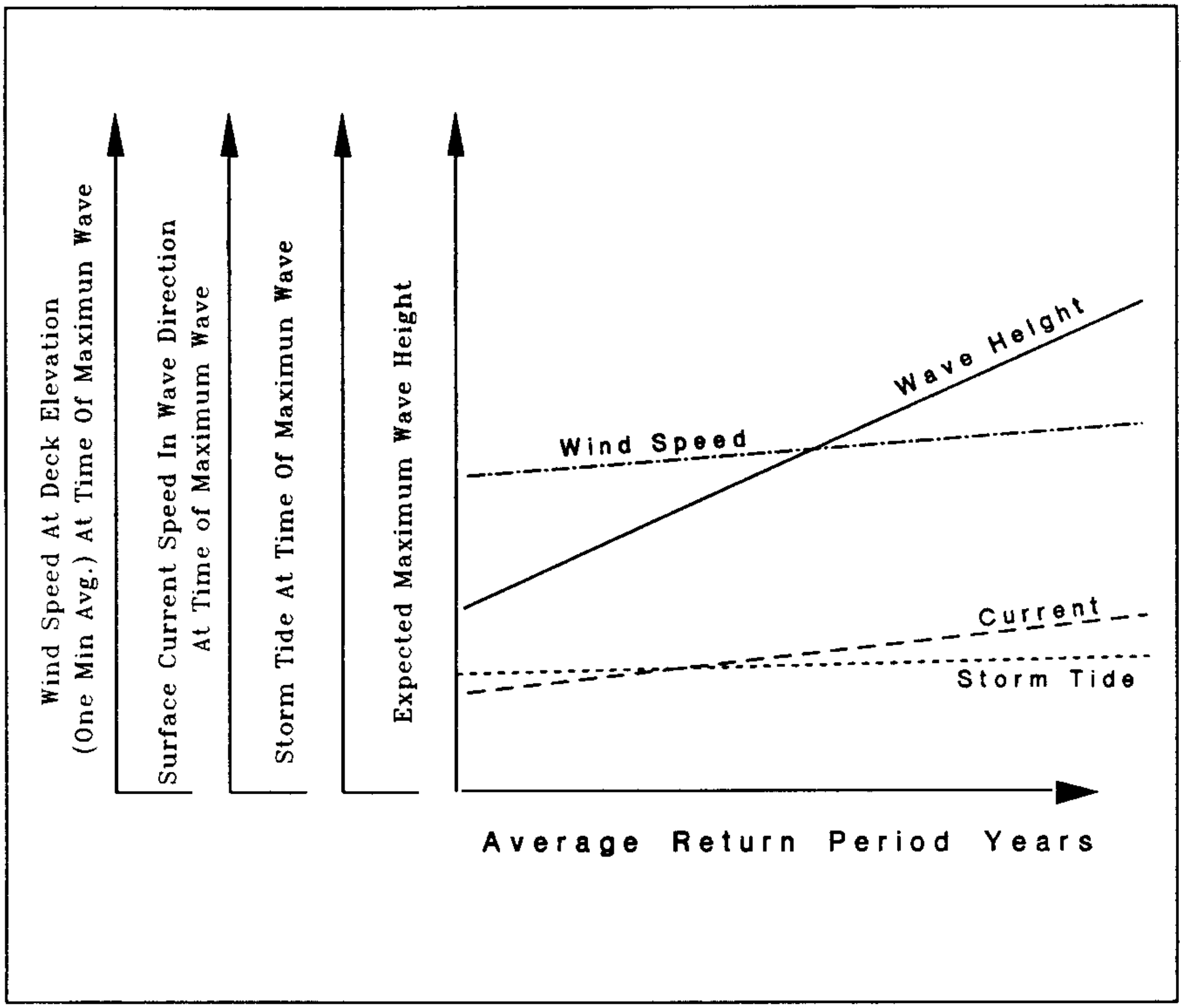
The wave-current velocities, V, are dependent on the wave heights, periods, water depths, directional spreadings, currents, and proximity to the wave free surface.

The guideline was illustrated by application to the decks of a platform that had failed during hurricane Hilda. The guidelines application predicted the failure that occurred.

Item	Height Ft.	Length Ft.	Width Ft.	Elev. of CG Ft.
Chemical/Engine Package	15	50	66	230
Quarters	12	66	35	243
Pipe on Rack	6	40	20	240
Skid Frame	5	35	42	225
Derrick Substructure	16	35	42	238
Mud Tank	20	45	15	232
V-Door Ramp	6	25	8	230
Derrick	Projected Area 97.5 Sq. Ft.			297

PLATFORM NO. 1 DECK EQUIPMENT

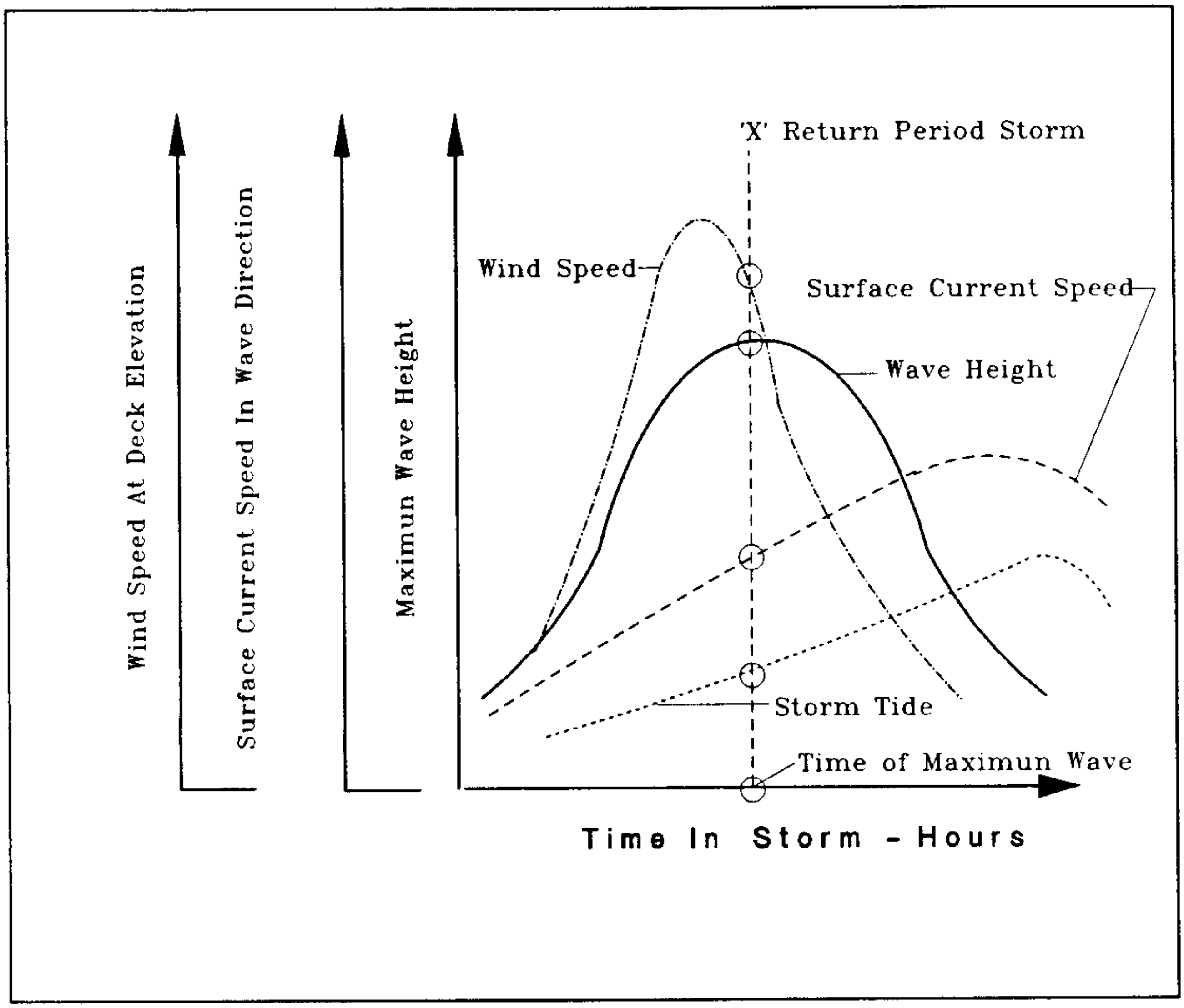
TABLE 7-1



AVERAGE RETURN PERIOD OF EXPECTED MAXIMUM WAVES, CURRENTS AND WINDS

FIGURE 7-1

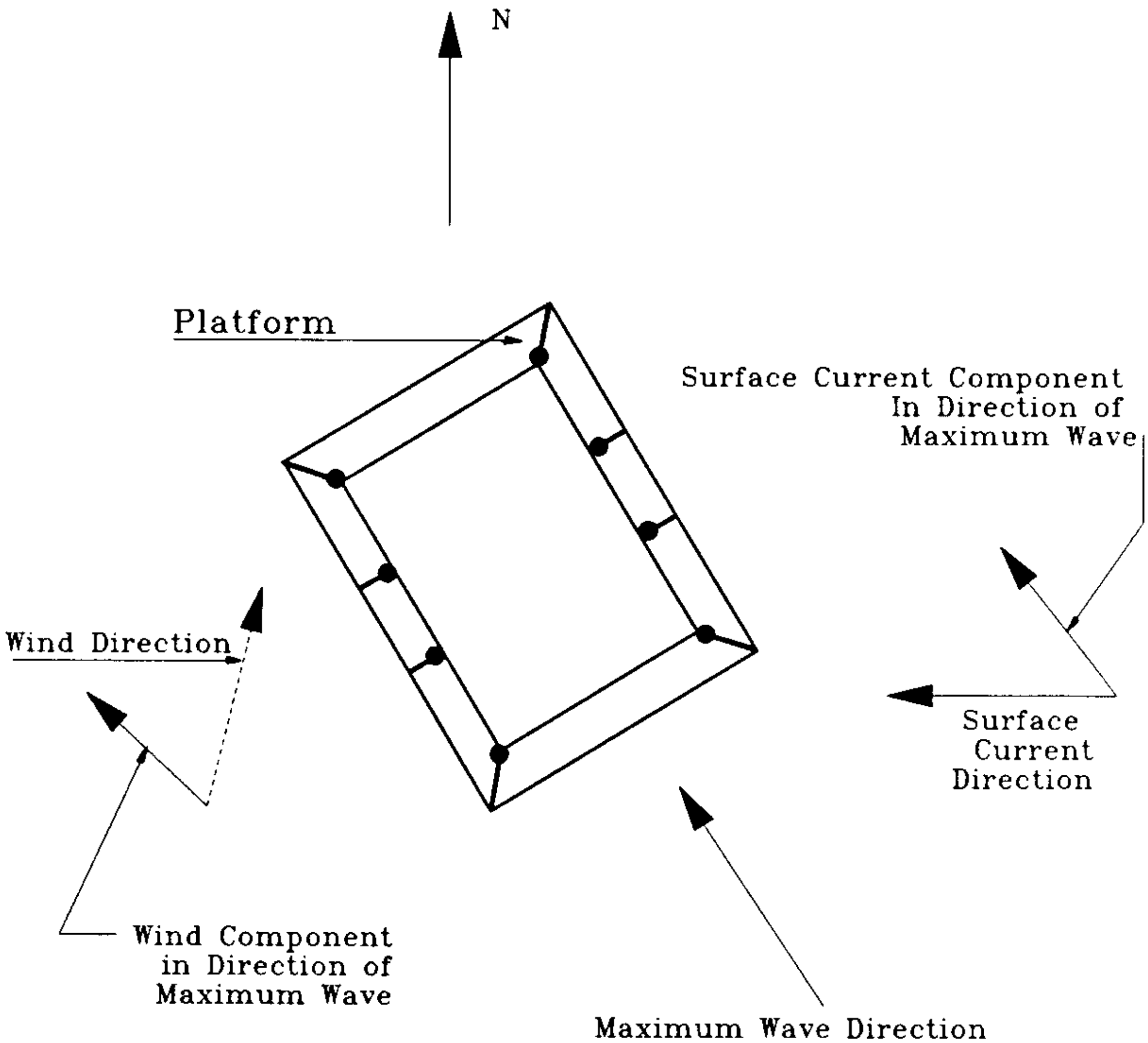
AIM3 FL\DISK.001 \AIM\AIM3-4.5\FIG-1.DRW



CURRENT AND WIND SPEEDS SPECIFIED AT TIME OF OCCURRENCE OF MAXIMUM WAVE

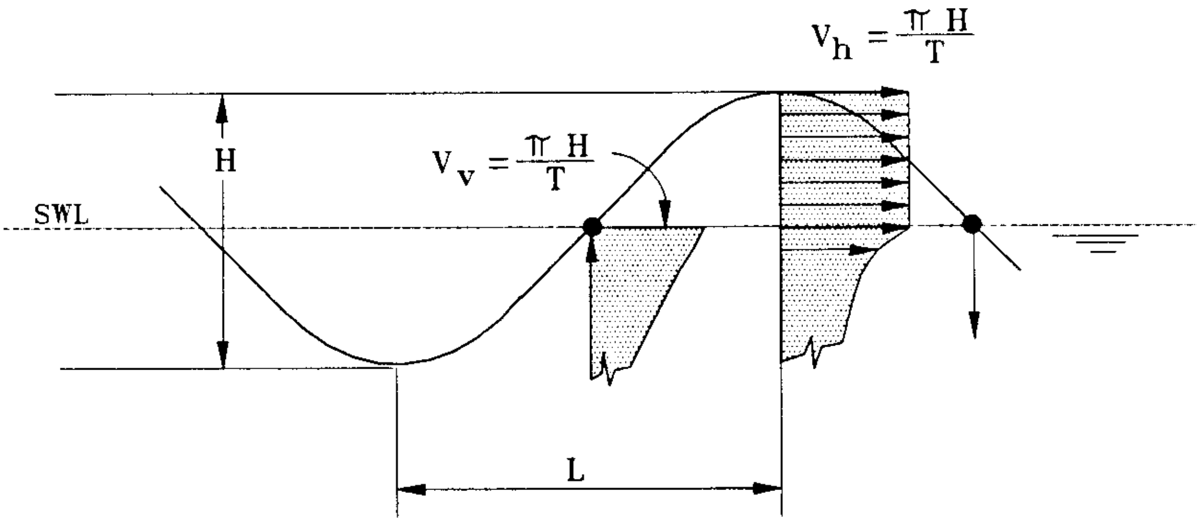
FIGURE 7-2

AIM3 FL\DISK.001 \AIM\FIG-2.DRW



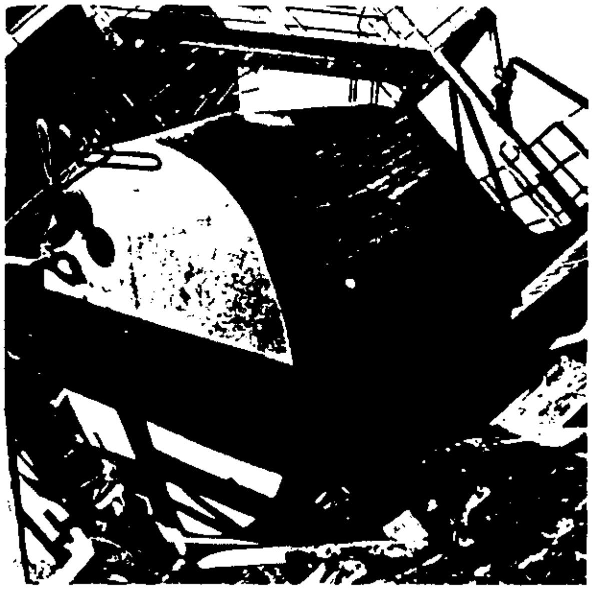
WIND AND CURRENT SPEED COMPONENTS IN SAME DIRECTION AS MAXIMUM WAVE

FIGURE 7-3

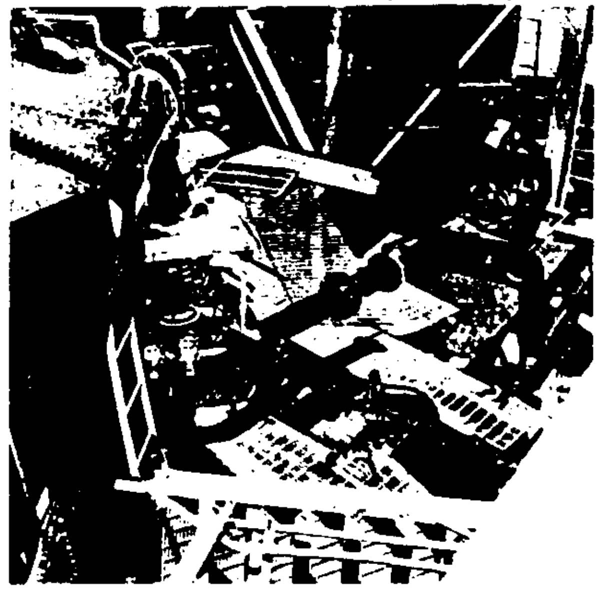


WAVE CREST KINEMATICS - DEEP WATER APPROXIMATION

FIGURE 7-4

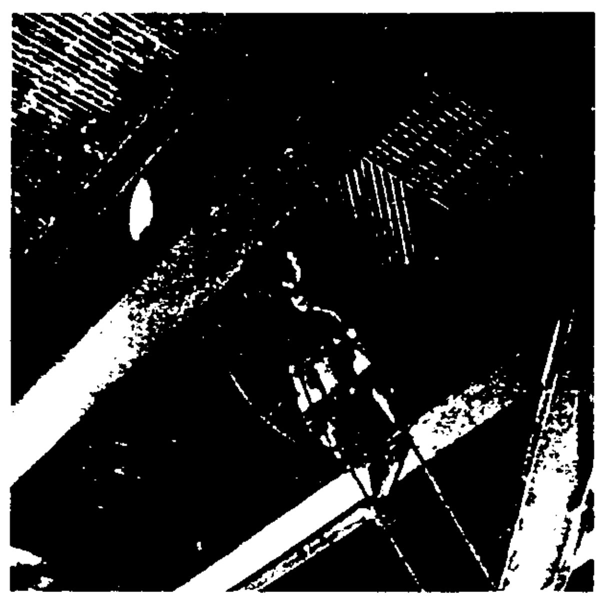


SP 62 B - 100 BBL. TEST TANK DENTED AND SWEPT FROM SKID BY WAVES (+50 FT.).



SP 62 B - TREATER-FLOTATION CELL TANK DENTED BY WAVES AND DEBRIS (+49 FT.). LADDER FROM S. END OF DECK.

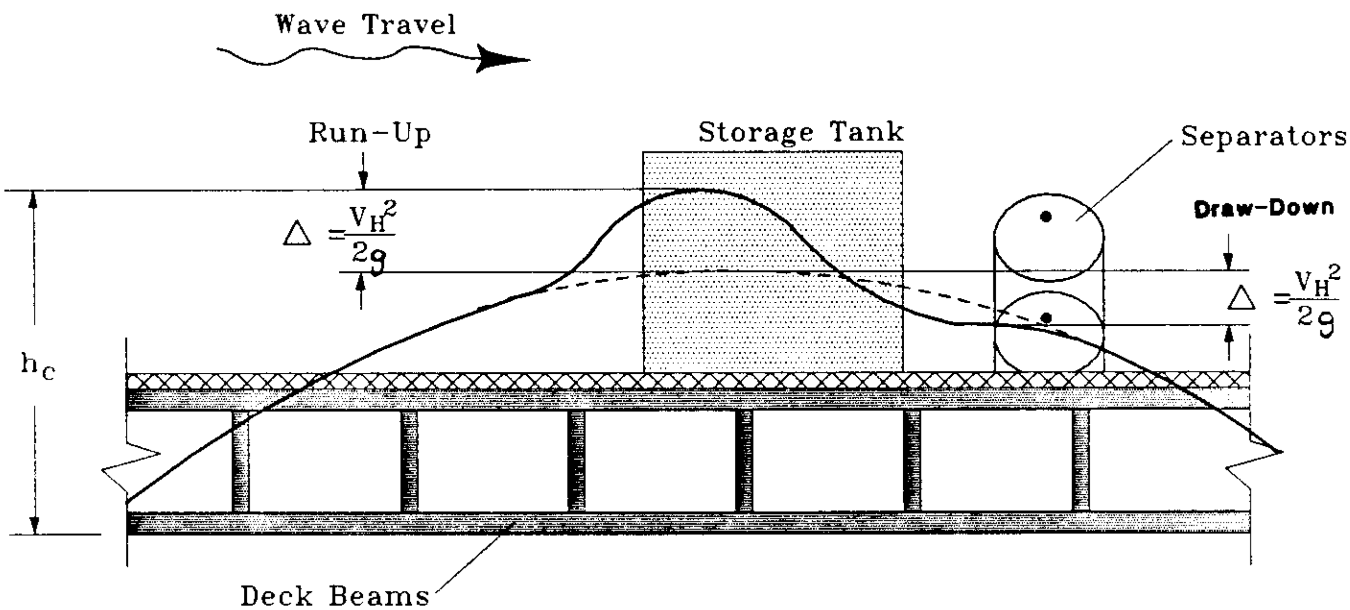
SP 62 B - SOUTH END OF LOWER DECK (+46 FT.). PIPE SPOOLS STACKED AGAINST WIND TRUSS.



SP 62 C - WAVE STAFF SUPPORT (+47 FT.). DECK BEAMS BENT, PAINT SCOURED OFF.

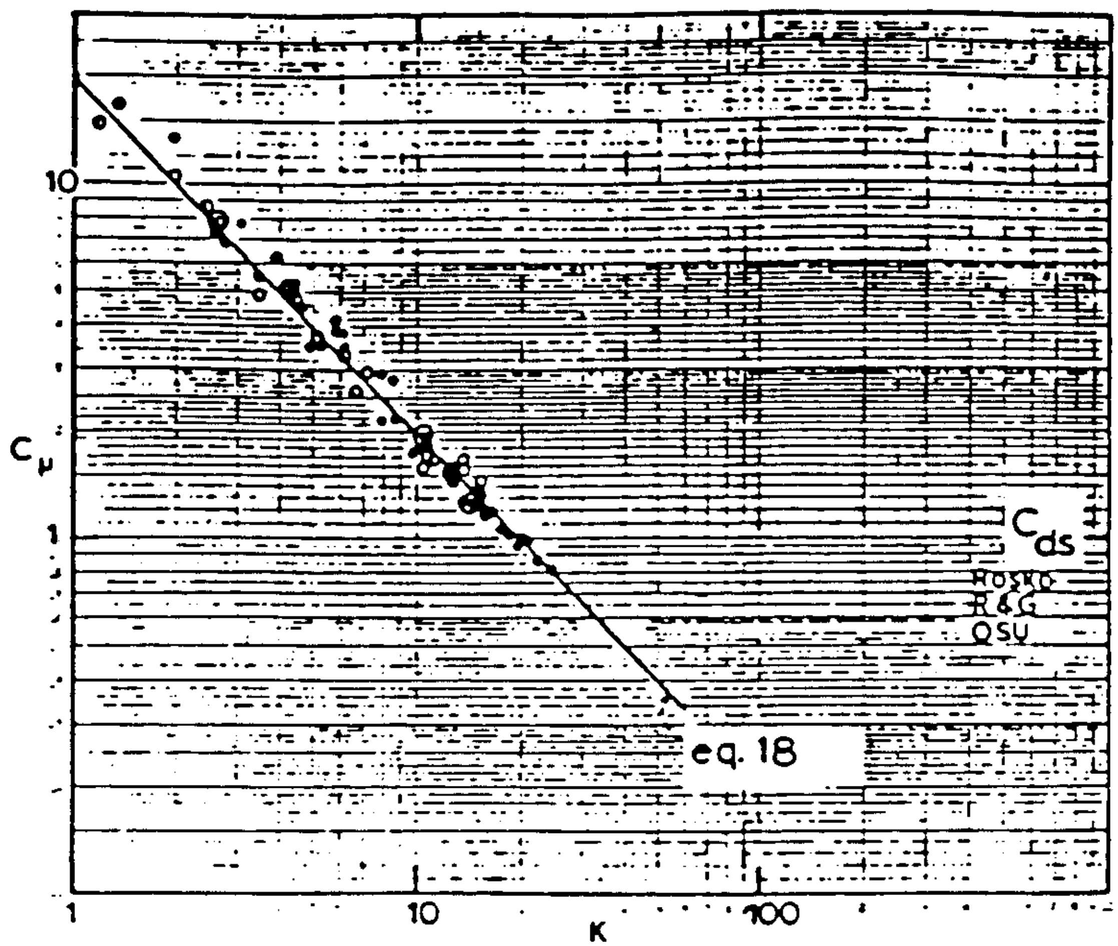
HURRICANE CAMILLE WAVE DAMAGE

FIGURE 7-5



WAVE CREST RUN-UP AND DRAWDOWN AROUND STORAGE TANK AND PLATFORM DECK

FIGURE 7-6



Maximum force coefficient for VSMC8 and VSMC12 cylinders. Values of C_m are from references [13 and 14] and from two tests at OSU; ● VSMC8, 6100 < β < 15000; ○ VSMC12, 13,000 < β < 40,000.

(eq. 18) $C_u = 2\pi^2 / K$ (small K) = Maximum Force Coefficient

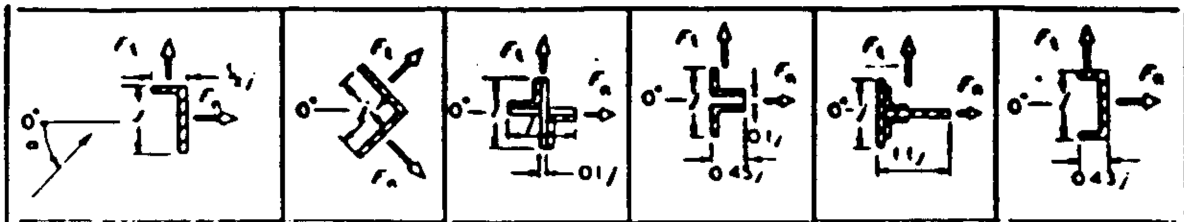
$C_u = C_{ds}$ (large K) (C_{ds} = Steady Flow Drag Coefficient)

$$C_u = \frac{F_u}{\frac{1}{2} D \rho U_u^2}$$

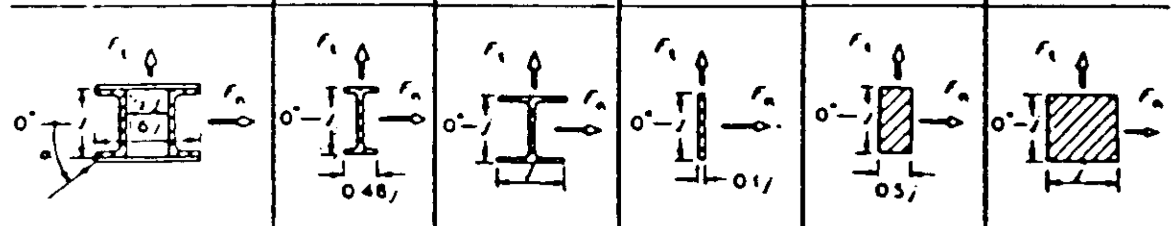
Fu = maximum horizontal wave force
U_u = maximum horizontal wave velocity

MAXIMUM FORCE COEFFICIENT TEST RESULTS

FIGURE 7-7



α degrees	C_n	C_t	C_n	C_t	C_n	C_t	C_n	C_t	C_n	C_t	C_n	C_t
0	+1.9	+0.95	+1.8	+1.8	+1.75	+0.1	+1.6	0	+2.0	0	+2.05	0
45	+1.8	+0.8	+2.1	+1.8	+0.85	+0.85	+1.5	−0.1	+1.2	+0.9	+1.85	+0.6
90	+2.0	+1.7	−1.9	−1.0	+0.1	+1.75	−0.95	+0.7	−1.6	+2.15	0	+0.6
135	−1.8	−0.1	−2.0	+0.3	−0.75	+0.75	−0.5	+1.05	−1.1	+2.4	−1.6	+0.4
180	−2.0	+0.1	−1.4	−1.4	−1.75	−0.1	−1.5	0	−1.7	±2.1	−1.8	0



α degrees	C_n	C_t	C_n	C_t	C_n	C_t	C_n	C_t	C_n	C_t	C_n	C_t
0	+1.4	0	+2.05	0	+1.6	0	+2.0	0	+2.1	0	+2.0	0
45	+1.2	+1.6	+1.95	+0.6	+1.5	+1.5	+1.8	+0.1	+1.4	+0.7	+1.55	+1.55
90	0	+2.2	0	+0.9	0	+1.9	0	+0.1	0	+0.75	0	+2.0

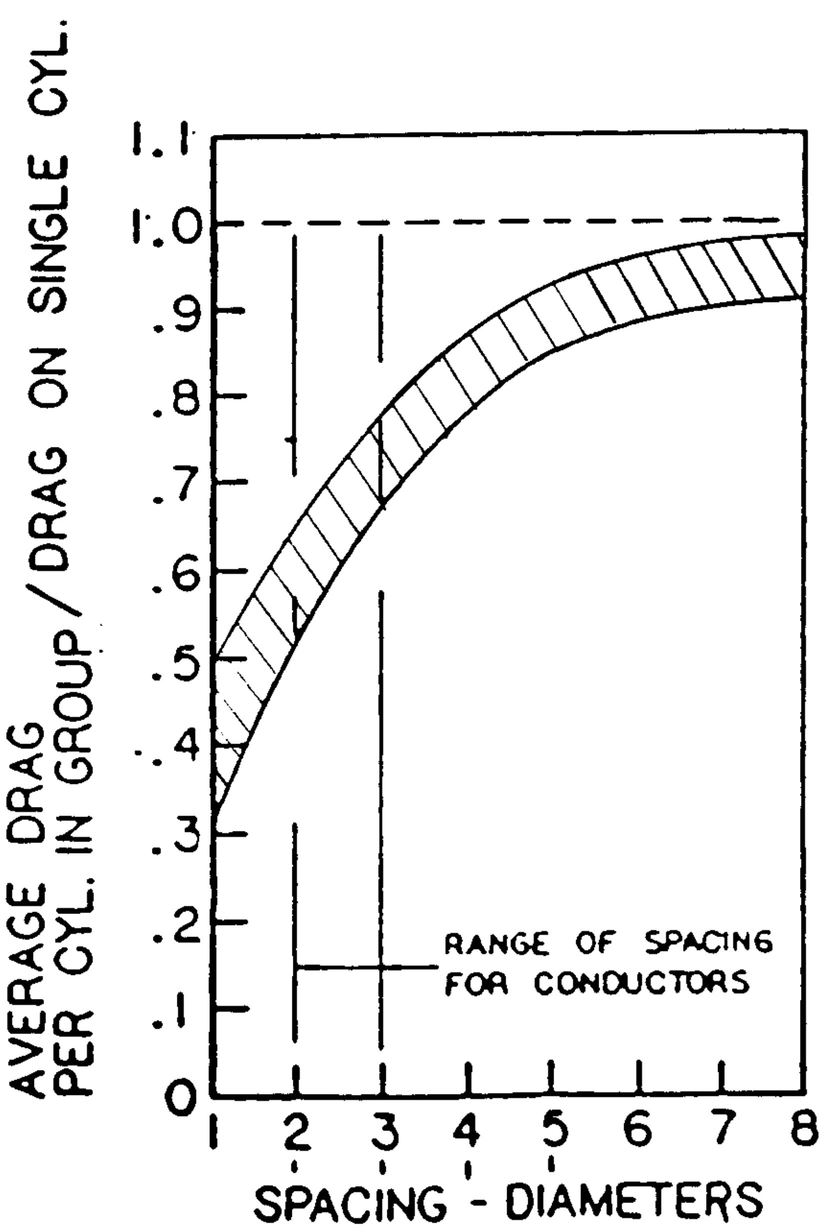
Note: In this table the force coefficient C_f is given in relation to the dimension j and not in relation to the effective frontal area A_e.

Values of reduction factor κ for member of finite length and slenderness.

ℓ/d	2	5	10	20	40	50	100	∞
Circular cylinder, subcritical flow	0.58	0.62	0.68	0.74	0.82	0.87	0.98	1.0
Circular cylinder, supercritical flow	0.80	0.80	0.82	0.90	0.98	0.99	1.0	1.0
Flat plate perpendicular to wind	0.62	0.66	0.69	0.81	0.87	0.90	0.95	1.0

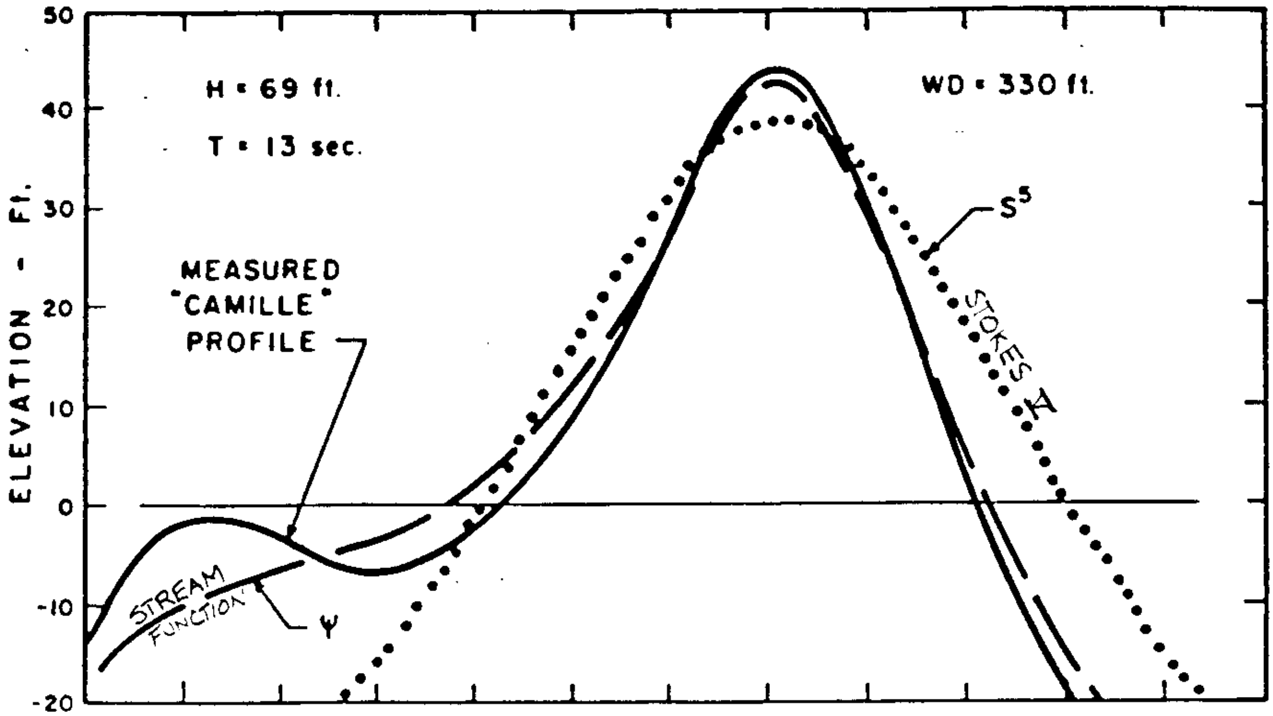
SHAPE COEFFICIENTS C_∞ FOR VARIOUS MEMBERS OF INFINITE LENGTH

FIGURE 7-8



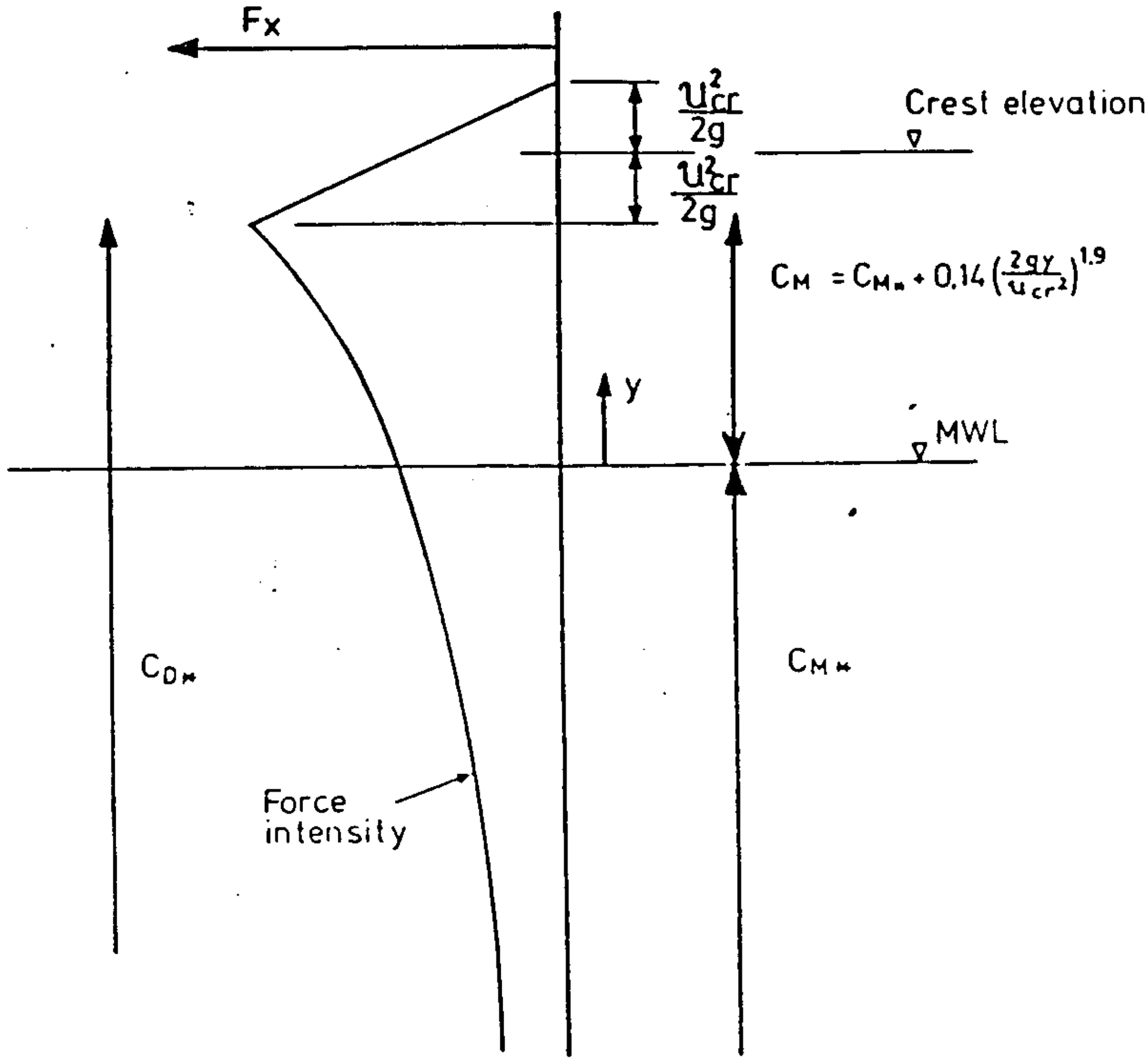
WAVE FORCES ON CLOSELY SPACED GROUPS OF CYLINDERS

FIGURE 7-9



MEASURED VERSUS THEORETICAL WAVE PROFILE

FIGURE 7-10



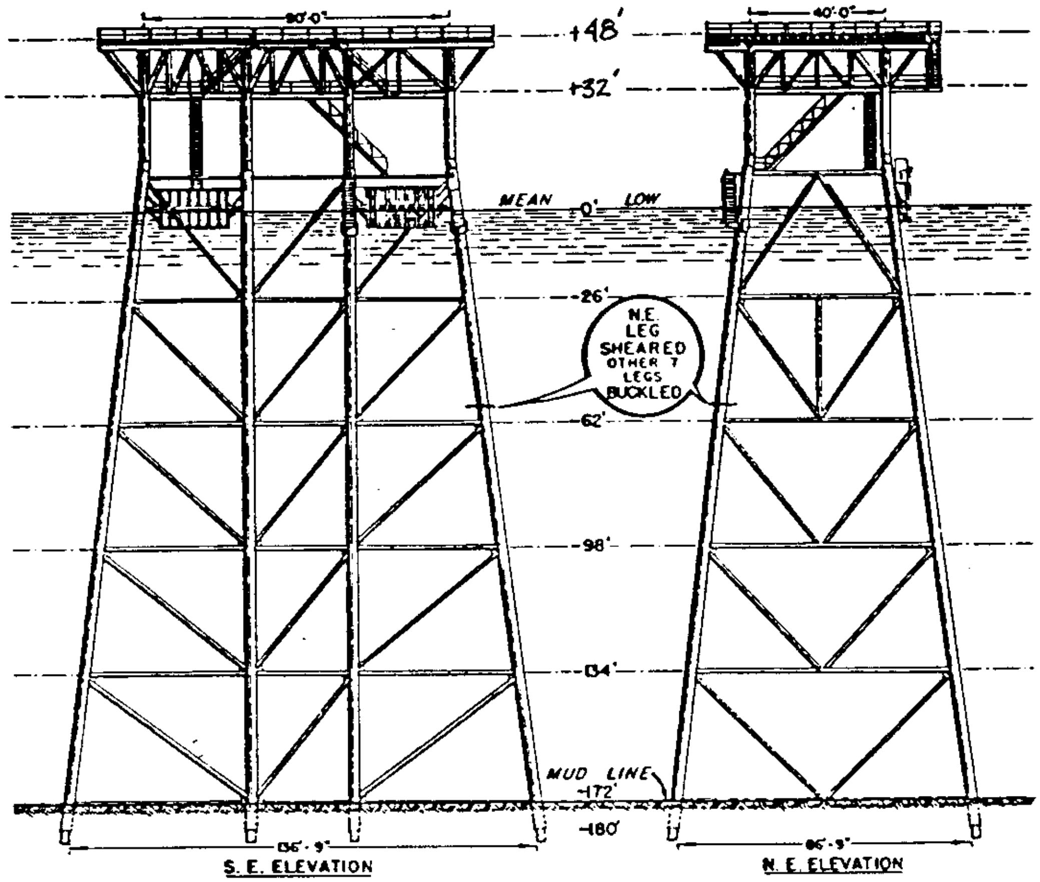
C_{D*} = } Values relevant to the prototype
C_{M*} = } Reynolds number and Keulegan Carpenter number

u_{cr} = Maximum water particle at the crest

Recommended design time invariant C_D and C_M values in the surface zone area.

KINEMATIC VARIATIONS NEAR WAVE CREST

FIGURE 7-11



Location - Central Gulf of Mexico

Water Depth - 172'

Type Platform - Minimum Self-Contained

Main Deck - 116' x 66' @ Elevation +48'

Cellar Deck - 60' x 40' @ Elevation +32'

Number of Wells - 12 (Installed - 3)

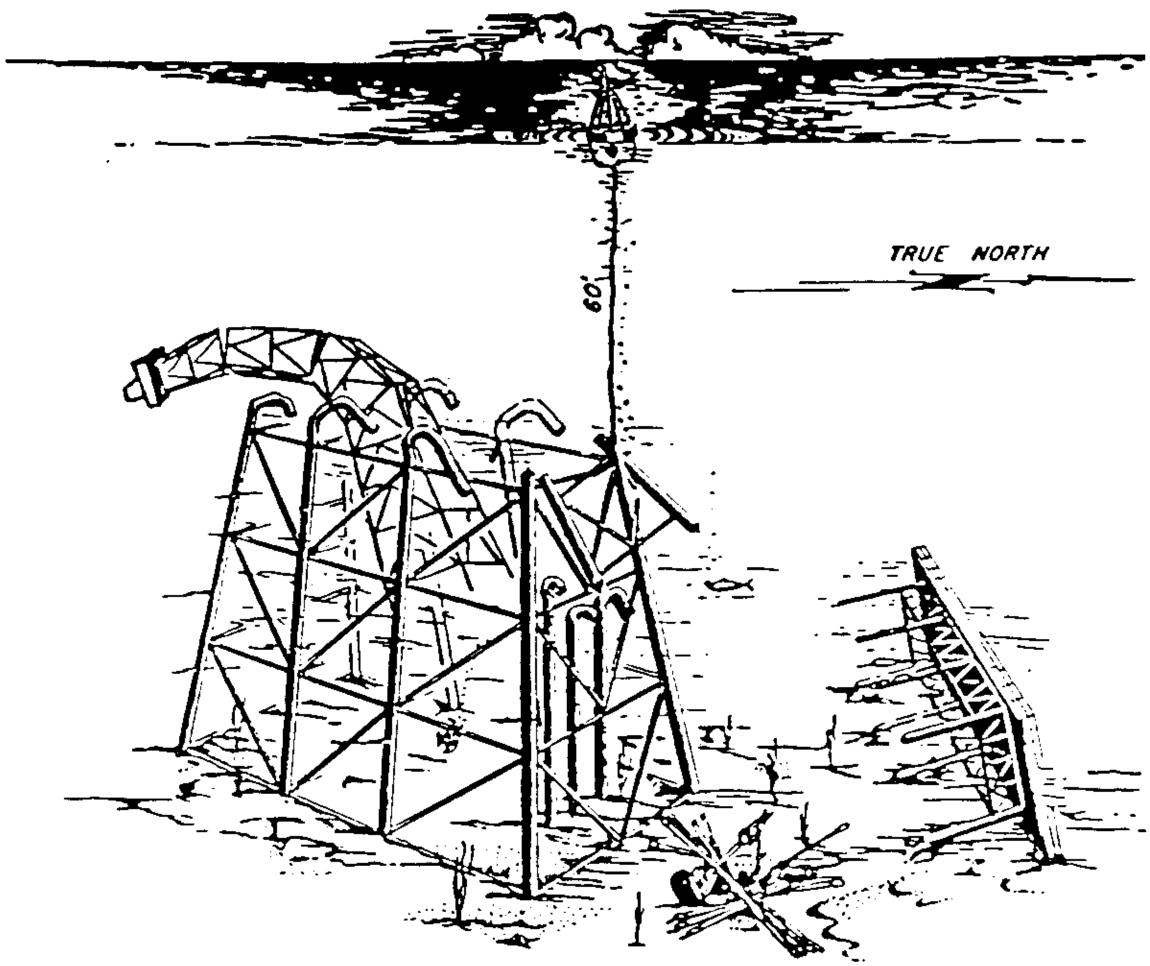
Piles - Eight 36" O.D.
Design Penetration - 145'

Design Criteria - Glenn 25-Year Storm
Crest Elevation +32'

Installation - 1964

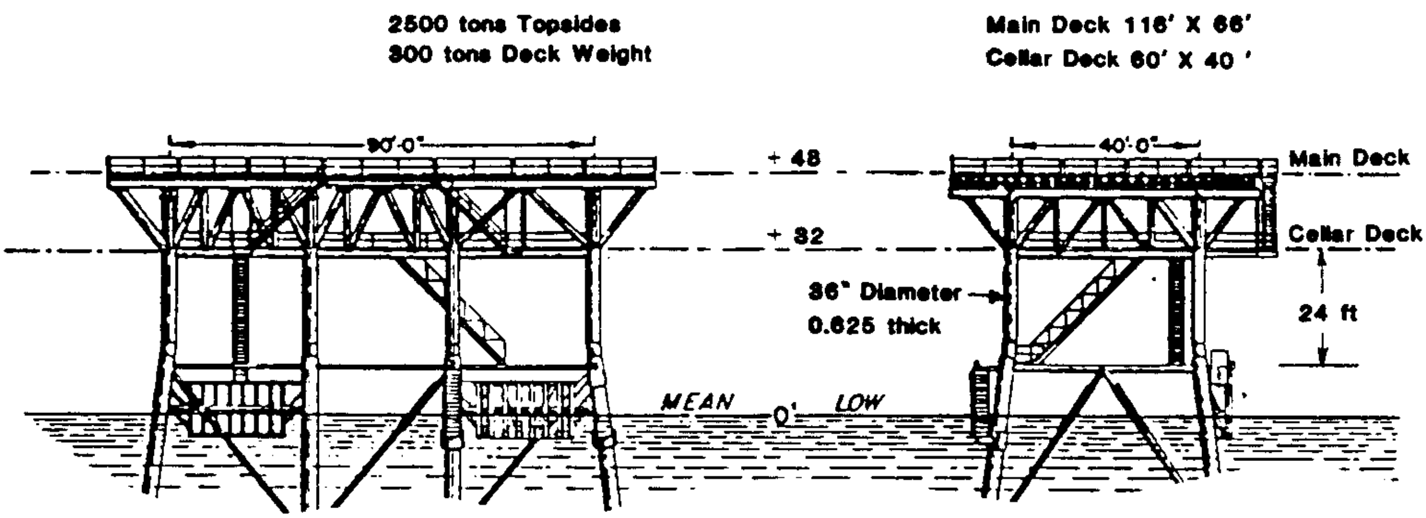
EXAMPLE PLATFORM CONFIGURATION

FIGURE 7-12



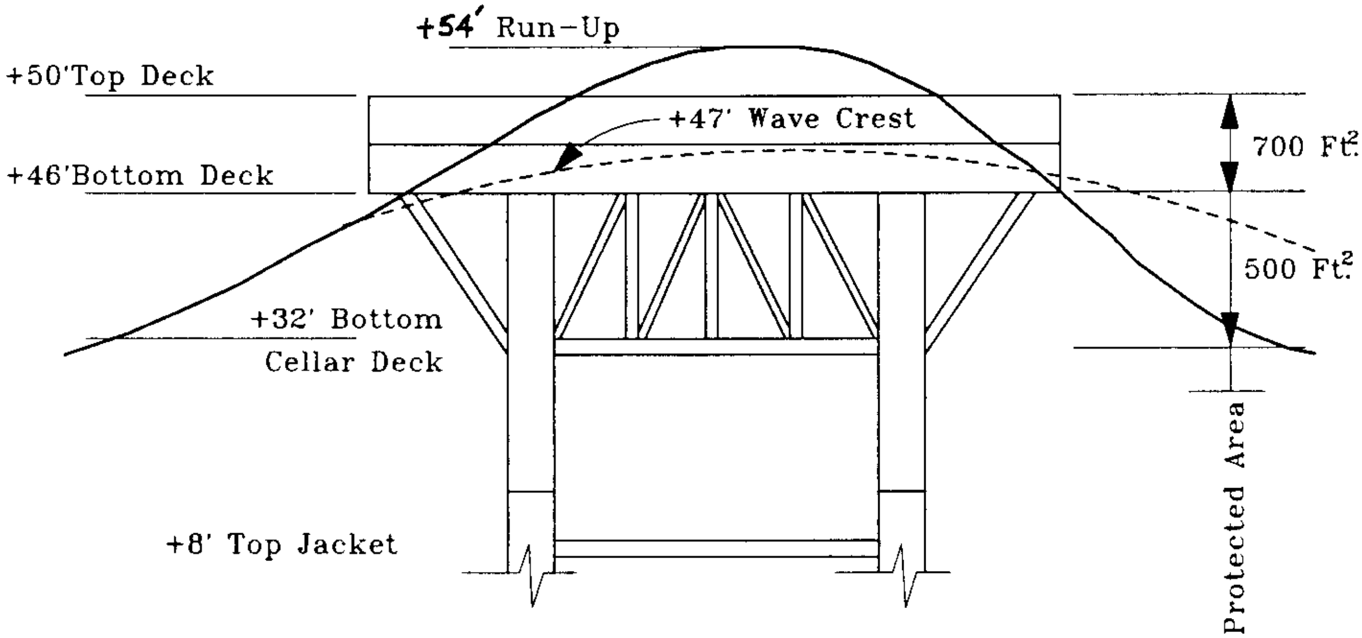
STORM DAMAGE TO EXAMPLE PLATFORM

FIGURE 7-13



DETAILS OF PLATFORM DECK

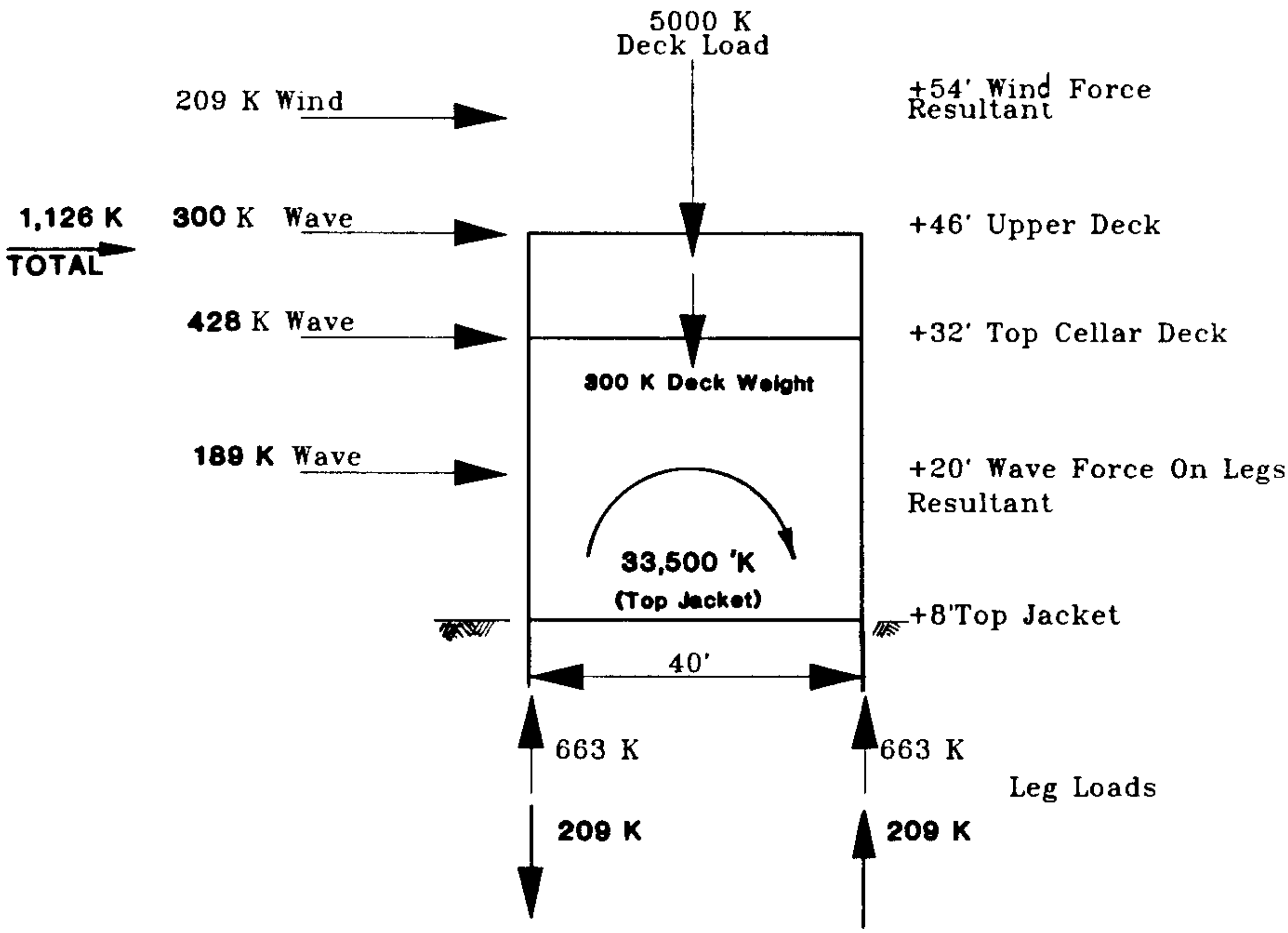
FIGURE 7-14



GEOMETRY OF PLATFORM, DECK, WAVE CREST, AND WAVE RUN-UP

FIGURE 7-15

AIM3 FL\DISK.001 \AIM\FIG-6.DRW



WAVE, WIND AND DECK LOAD SYSTEM ACTING ON PLATFORM

FIGURE 7-16

8.0 SUMMARY COMPARISONS

This section provides a summary comparison of the intact and damage case condition assessments for Platform "C." The intent is to review the overall effect on the platform due to the damage conditions and determine which damage cases most severely influenced the platform's capacity.

Figure 8-1 compares all of the damage cases against the intact case for wave loading in the end-on X-directions. The loading profile used in all of the analyses considered wave loading in the deck. Overall the damage cases did not severely influence the platform's response (e.g no capacity reductions on the order of 50 to 75 percent). The platforms capacity was reduced in all cases with a maximum reduction of about 34 percent caused by the overall platform corrosion condition. For this loading direction, the capacity did not drop below the 100 year wave force for any damage case. The platform appeared to be fairly resilient to the investigated damage conditions.

Figure 8-2 shows similar results for loading in the broadside Y-direction. Again there were no large capacity reductions; however, the platform's capacity appears more severely affected by damage when considering this direction. The maximum capacity reduction was 34 percent caused by the overall platform corrosion condition. This corrosion condition also left the platform with insufficient capacity to resist 100-yr wave loading.

Table 8-1 summarizes the analysis cases for all loading conditions and damage cases. The platform's RSR is about 1.4 to 1.6 for the intact condition. The worst damage condition is the total platform corrosion case which leaves the platform with an RSR in the range of less than 1.0, indicating the damaged platform will not survive a 100-yr return period storm.

This study only investigated a few of the many damage conditions that might occur for this platform. Other cases may consider different damaged members (diagonals at mudline), multiple damaged members (3 diagonals damaged) and different types of damage (corrosion holes, joint cracks). These damage cases may have a more pronounced effect on the platform's capacity than was found for the damage conditions investigated in this study.

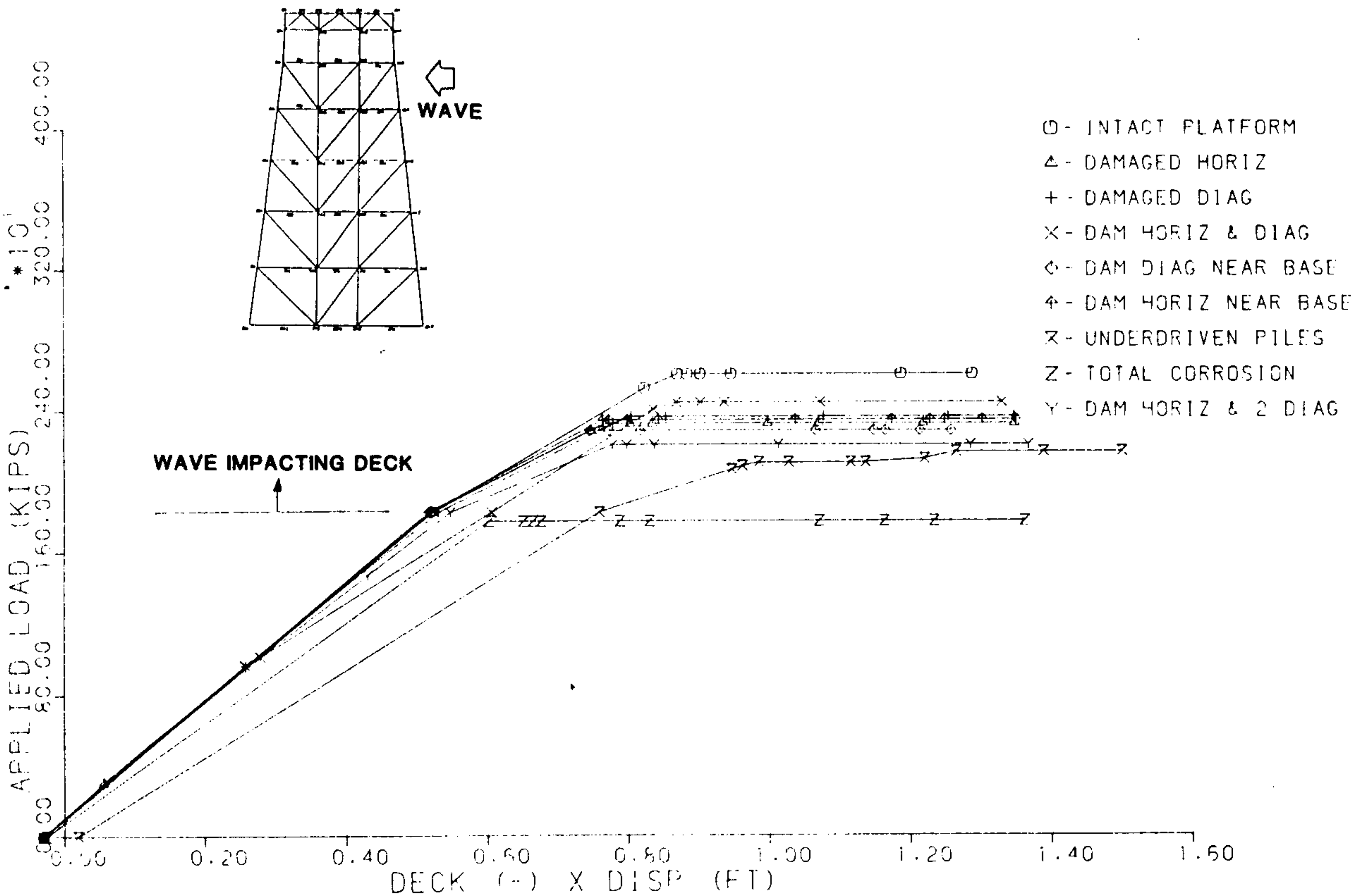
Damage Case	Loading	Capacity	Capacity Reduction	RSR*	
				CD=0.7	CD=0.6
Intact - No Damage	End-on Broadside	2600 2940	--- ---	1.42 1.30	1.63 1.60
Dented/Bent Horizontal	End-on	2330	11%	1.27	1.46
Dented/Bent Diagonal	End-on	2370	10%	1.30	1.48
Dented/Bent Horiz & Diag	End-on	2450	6%	1.34	1.53
Dented/Bent Horiz and Two Diags	End-on	2210	15%	1.21	1.38
Missing Horiz Near Base	End-on	2350	10%	1.28	1.47
Missing Diag Near Base	End-on	2290	12%	1.25	1.43
Interior Horiz & Diagonal Damage	Broadside	2320	21%	1.03	1.25
Total Platform Corrosion	End-on Broadside	1780 1950	32% 34%	0.97 0.86	1.11 1.05
Splash Zone Corrosion	Broadside	2400	18%	1.06	1.30
Underdriven Piles	End-on Broadside	2170 2820	17% 5%	1.19 1.25	1.36 1.52

RSR = Reserve Strength Ratio = ULS Capacity/Reference Load

Reference Load = API 100 Yr Load
($C_d = 0.6$) = 1600 k - X-direction
1850 k - Y-direction
($C_d = 0.7$) = 1830 k - X-direction
2260 k - Y-direction

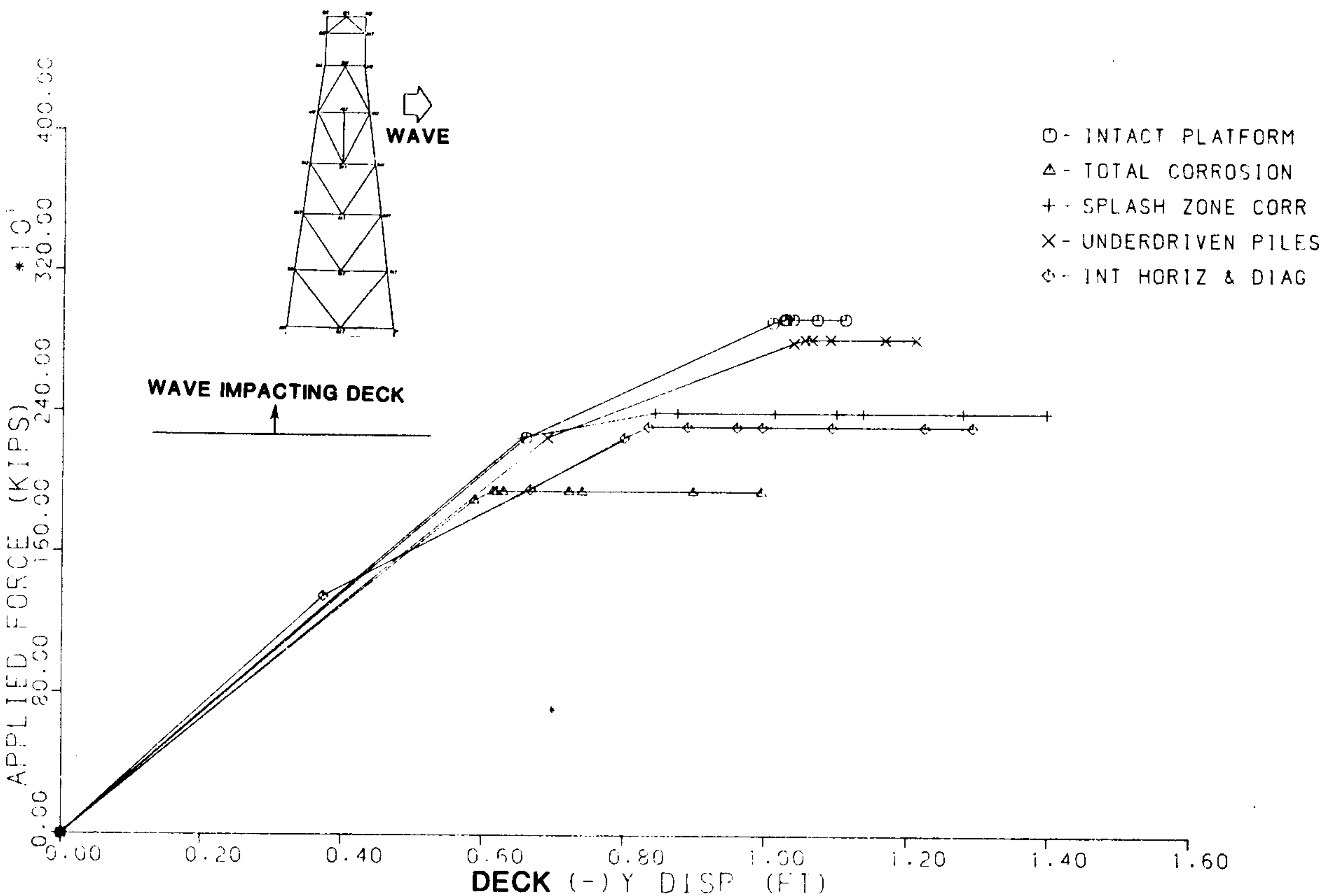
SUMMARY OF PLATFORM "C" - INTACT AND DAMAGE CASE ASSESSMENTS

TABLE 8-1



SUMMARY OF DAMAGE CASE RESULTS FOR END-ON PLATFORM LOADING

FIGURE 8-1



SUMMARY OF DAMAGE CASE RESULTS FOR BROADSIDE PLATFORM LOADING

FIGURE 6-2

9.0 CONCLUSIONS

9.1 Platform Performance

Platform "C" was chosen because it represents a large number of typical platform currently operating in the Gulf of Mexico. The individual damage cases investigated also represent typically observed damage on these types of platforms. The intent is to provide operators with an initial assessment of the effects on platform capacity due to one of these types of damage. In a sense, this information provides an initial set of data for a "damage condition" library for offshore platforms. Other future studies may extend this database by using different types of platforms and different damage conditions.

Some of the major conclusions from each of the key capacity assessments are summarized as follows:

Intact Condition: Although designed for only a 58-ft wave instead of today's more severe 70 ft wave, the platform performed quite well with an RSR of about 1.5. However, the deck level is still low and there may be some severe damage for a 100-yr wave which just begins to impact the deck. The platform appears to be able to generally survive about a 200-yr return period wave condition, even with the waves impacting some of the lower deck.

Damaged Members Near Waterline: Damage in this case was limited to 1 to 3 members that were dented and bent due to workboat impacts. Capacity of the platform dropped about 5 to 15 percent depending upon the number of damaged members and their proximity to each other. The largest reduction was for a case of three damaged members in the same area that affect each other's load resistance contribution.

Damage Near Base of Jacket: This case considered a completely severed member near the base of the jacket as a result of dropped debris from drilling operations. The first case considered a severed horizontal and the second case considered a severed diagonal. Platform capacity was reduced by about 10 to 12 percent, with the missing diagonal having the greatest effect.

Interior Horizontal Damage with Diagonal Damage: This case investigated several missing interior horizontals combined with a dented and bent diagonal along Row 1. This damage resulted in a platform capacity reduction of 20 percent, indicating more severe damage than in the previous cases. It appears that most of the strength reduction was due to the damaged diagonal. This indicates that damage to members perpendicular to the broadside platform direction may have a pronounced effect on platform capacity.

Corrosion Damage: This case considered overall corrosion (1/8 inch) throughout the entire platform and local severe corrosion (1/4 inch) in the splash zone. The overall platform corrosion resulted in a capacity reduction of 34 percent which is the largest for any damage case study. This is caused by the effective loss of capacity in every platform member due to the corrosion. The splash zone corrosion condition resulted in a less severe capacity reduction of about 20 percent. Unfortunately, both of these conditions are some of the most prevalent damage conditions found in these types of platforms.

Foundation Defects: This damage or "defect" consisted of underdriven piles along Row 1 that met refusal at 150 ft penetration instead of the design penetration of 270 ft. Platform capacity dropped from 5 to 17 percent for this condition depending upon loading direction. Given that this damage occurs during installation, with a full platform life still ahead, the operator would likely choose to repair this defect by insert piles or other means.

9.2 Ultimate Limit State Procedures.

This study measured the effects of platform damage based upon changes in the platform's Ultimate Limit State (ULS) capacity. The proper determination of ULS capacity requires a sophisticated computer code capable of mimicking the performance of members in their post elastic state. Other specialities are required as well, such as damaged member computer modeling and wave loading of deck elements when studying older platforms. Some conclusions regarding these issues are as follows:

ULS Analysis: There is still a considerable amount of time required to develop the fully nonlinear model for this analysis. Pile-soil, strut, and nonlinear beam-column characteristics must be developed and input to the computer model. The analysis itself has been simplified and automated due to the utilization of a special solution strategy as discussed in Section 4.2. PMB is currently working on techniques to simplify the computer model development stage as well as increased automation in the solution process.

ULS Verification/Calibration: There is a need to verify/calibrate the ULS analysis approach against some known conditions. One of the work efforts of the proposed AIM IV project [34] is the use of two platform's for a ULS calibration. Both platforms experienced the same storm with one platform completely failing and the other surviving, but severely damaged. These platform's would provide an excellent verification requiring the computer simulation to predict one platform failure and one platform survival for the same storm.

Damaged Members: This study used the DENTA laboratory results for modeling dented and bent members. Tests by others provide alternative sources of damaged member data. There are other damage conditions that are of concern such as corrosion holes, cracks in members and cracks at joints. Overall, there appears to be a need for more damaged member investigations. PMB is currently directing a damaged member study that uses actual platform members tested under laboratory conditions [35].

Joint Capacity: Joint capacity was not a major issue for this study since the piles were grouted to the jacket legs creating an effective heavy wall section. However, this is not always the case and joint punching may often control in older platforms that are typically configured with no joint cans or grouted legs. This requires adequate predictions of joint capacity. There appears to be sufficient data for punching, but little data for tension "tear" or strengths of grouted pile-leg connections. Conservative rule-of-thumb approximations are often used for grouted connections. A comprehensive joint capacity program by the industry is recommended.

Waves Acting On Deck Elements: This study made a first approximation of a refined methodology for determining wave loads acting on deck elements. Wave action on decks is an important item for older platforms. A more concentrated effort, perhaps backed by laboratory testing, is warranted.

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APPENDIX

PLATFORM "C" MISCELLANEOUS ITEMS

1. Relative Displacement between Mudline and Deck

Figure A-1 shows displacements at the mudline and the deck for platform loading on the broadside Y direction. The relative "jacket" displacement is approximately 1 foot at the onset of member failures. The mudline displacement is rather small due to the sandy soils at the site. Complete failure of the platform (inability to carry vertical or lateral loads) occurs at about 1.3 feet of deck deflection.

Figure A-2 shows similar results for the end-on X-direction. The relative "jacket" displacement is slightly less than 1 foot at the onset of member failures. Complete failure of the platform occurs at about 1.5 ft of deck deflection.

2. Vertical Displacement at the Deck

Figure A-3 shows vertical displacements at the deck for platform loading on the broadside Y direction. Figure A-4 shows similar results for the X direction. Displacements are shown for points located at opposite ends of the deck. The deck moves downward approximately 1 to 2 inches during the analysis.

3. Deck Payload and Distribution

Deck	=	600 Tons
Topsides	=	5500 Tons
Total		6100 Tons

Weight is equally distributed between the eight platform legs.

4. Contribution of Conductors in Resisting Wave Loads

The conductors are modeled with a complete foundation for resisting lateral loading (P-Y). They are laterally connected to the jacket at the horizontal elevations by conductor guides; however, they can move separately from the jacket in the vertical direction. There are 24 conductors with 22" diameter and 1/2 inch wall thickness.

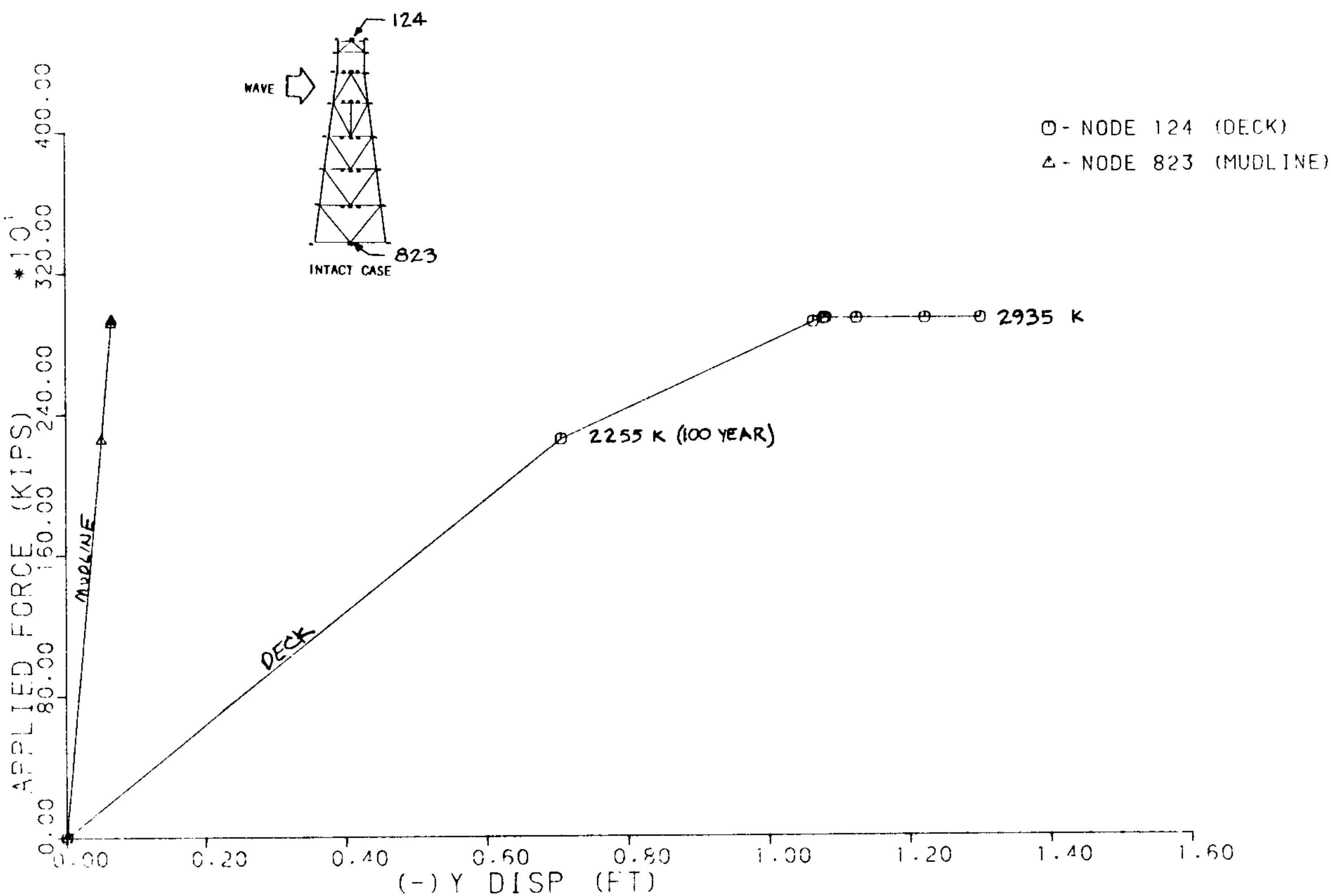
Figure A-5 summarizes data associated with conductor contribution to platform resistance and wave loading on the conductors. The conductors are seen to contribute about 20 percent of the total resistance to loading at time of platform failure. The load on the conductors at this time is about 10 percent of the total load on the platform (including deck loads). Thus the net contribution of the conductors, in terms of contributing to "jacket" resistance is about 10 percent of the applied load. Note that these values are for the loading at platform failure, and may be different at other loading levels.

5. Loads in Interior Horizontals

Figure A-6 shows a plan view of the interior horizontal framing at elevation -40 ft. Figures A-7 and A-8 show loads and interaction ratios (IR's) for these members for end-on (X direction) and broadside (Y direction), respectively. The loads are the maximum loads that occurred in the member during the course of the ULS analyses. The IR's are typically quite low, with a maximum of .34.

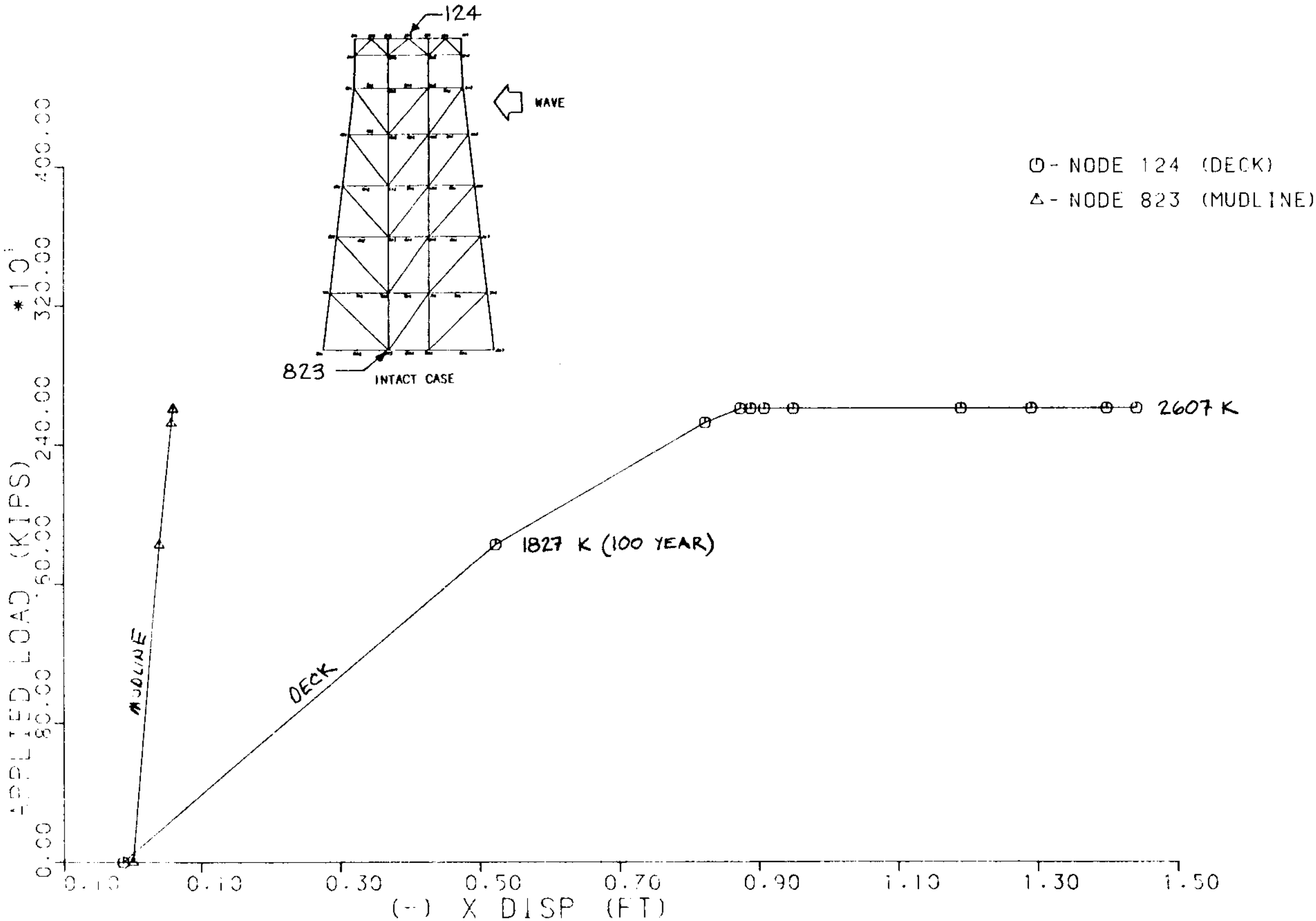
6. Member Sizes and Decreased Thickness Near Splash Zone for Damage Case Number 5 - "Splash Zone Corrosion"

Figure A-9 shows the typical member sizes near the splash zone and their thickness reduction for Damage Case Number 5.



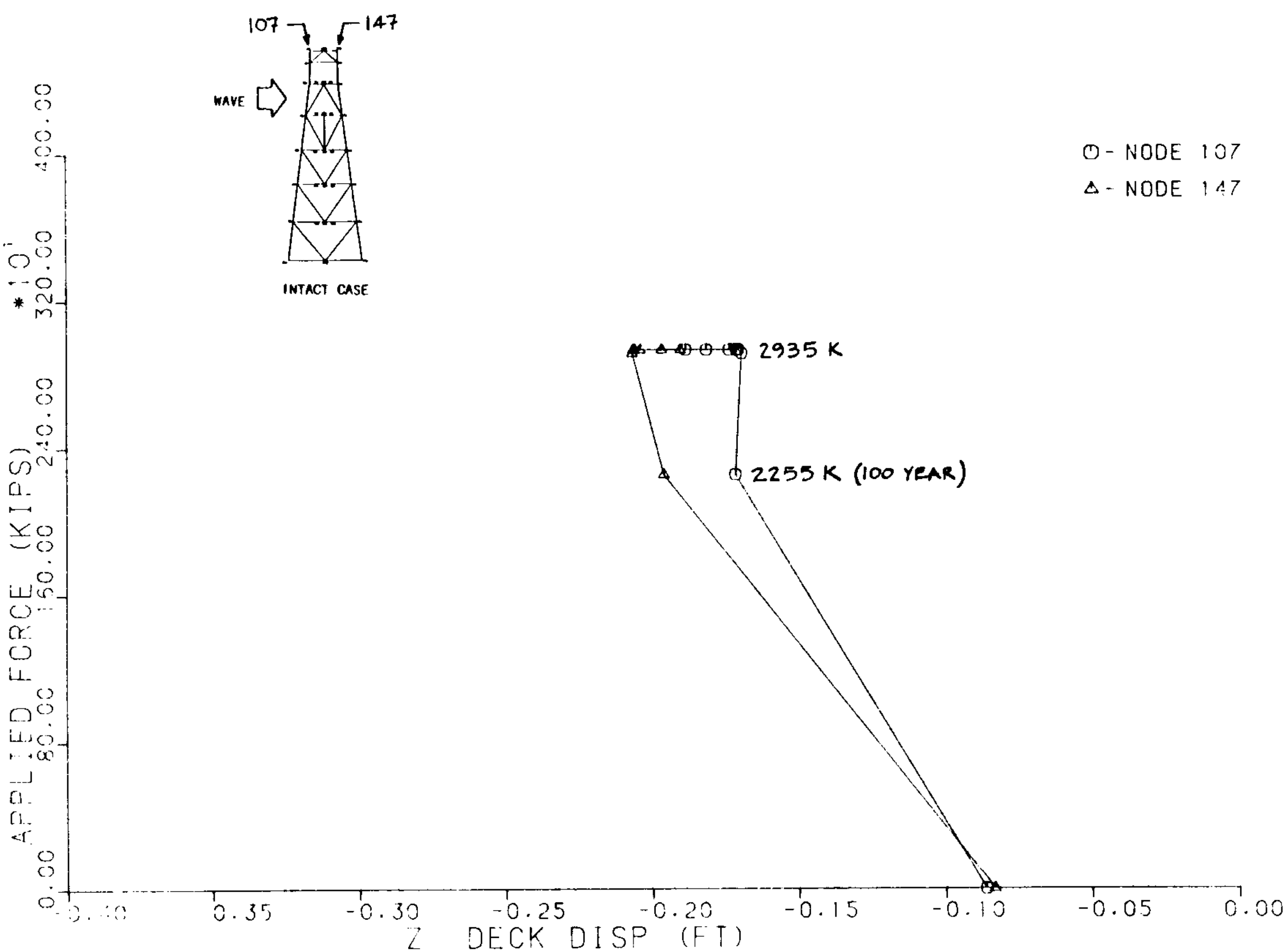
AIM3, 271' W/D, -Y 200 YR WAVE, WAVE ON DECK

A-1

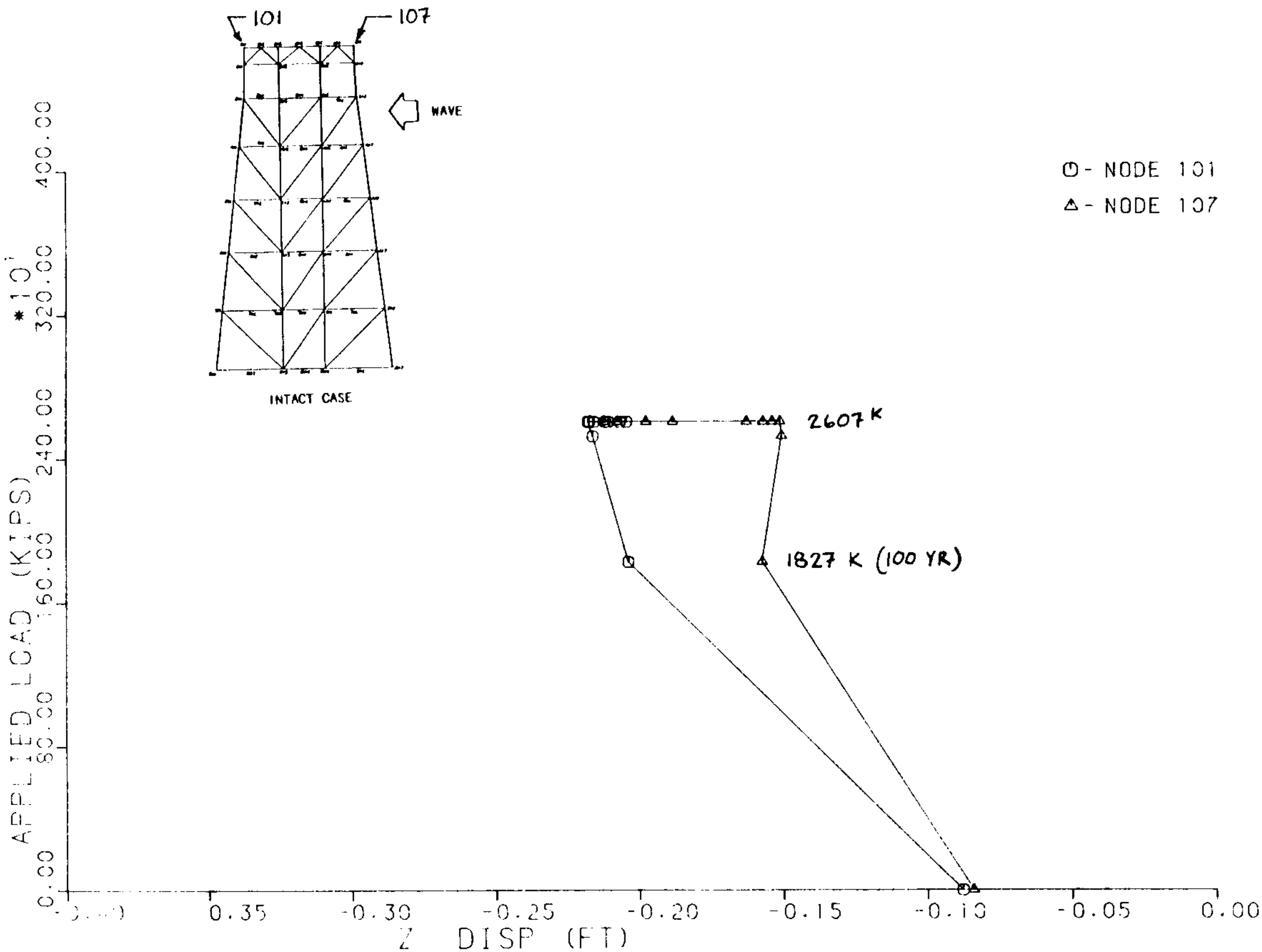


AIM3, 271' WD -X 200 YEAR WAVE WAVE ON DECK

A-2



AIM3, 271' W/D, -Y 200 YR WAVE, WAVE ON DECK



AIM3, 271' WD -X 200 YEAR WAVE

A-4

SHEAR LOAD IN CONDUCTORS - BASE SHEAR

(-)Y DIR 200 YR WAVE
T= 135.0 SEC

PILE SHEAR : 2394 K
CONDUCTOR SHEAR : 541 K
@ mudline

TOTAL: 2935 K

% CONDUCTOR = $\frac{541}{2935}$ = 18 %

% PILE = $\frac{2394}{2935}$ = 82 %

(-)X DIR 200 YR WAVE : - BASE SHEAR

T= 220.0 SEC

PILE SHEAR : 2042 K
CONDUCTOR SHEAR : 565 K
@ mudline

TOTAL: 2607 K

% CONDUCTOR = $\frac{565}{2607}$ = 22 %

% PILE = $\frac{2042}{2607}$ = 78 %

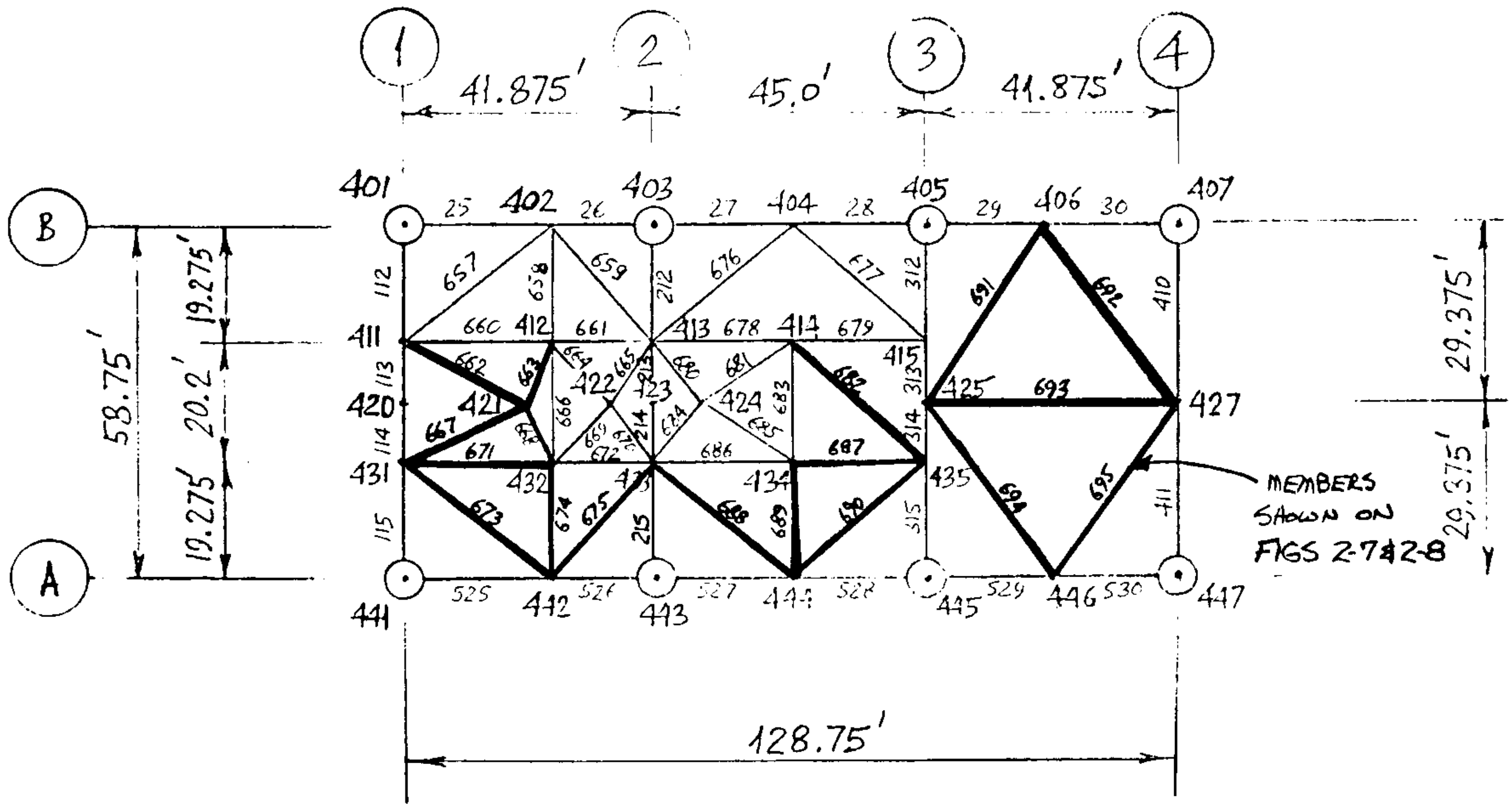
200 YR WAVE LOAD ON CONDUCTOR NODES

CONDUCTOR NODE	(−)X DIR WAVE LOAD	(−)Y DIR WAVE LOAD
221	−.00959	−.01094
222	0 (say .00959)	0 (say −.01094)
224	0 (say .00959)	0 (say −.01094)
321	−.00926	−.00957
322	−.01024	−.00957
324	−.01095	−.00957
421	−.00664	−.00674
422	−.00729	−.00674
424	−.00776	−.00674
521	−.00337	−.00337
522	−.00368	−.00337
524	−.00390	−.00337
621	−.00174	−.00172
622	−.00189	−.00172
624	−.00199	−.00172
721	−.00118	−.00114
722	−.00127	−.00114
724	−.00134	−.00114
821	−.00050	−.000484
822	−.00054	−.000484
824	−.00057	−.000484
TOTAL:	.10288	.101892
% OF APPLIED WAVE LOAD:	10.3 % *	10.2 % *

* NOTE: TOTAL WAVE LOAD WAS NORMALIZED TO 1.0.

CONCLUSION: CONDUCTORS PICK UP ~20% OF BASE SHEAR ⇒ THEY ARE ABSORBING SOME OF THE WAVE LOADS ON THE JACKET.

PLAN @ EL. -40.0'


1
2
3
4
A
B
41.875'
45.0'
41.875'
128.75'
58.75'
19.275'
20.2'
19.275'
29.375'
29.375'
401
402
403
404
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447
MEMBERS
SHOWN ON
FIGS 2-7&2-8

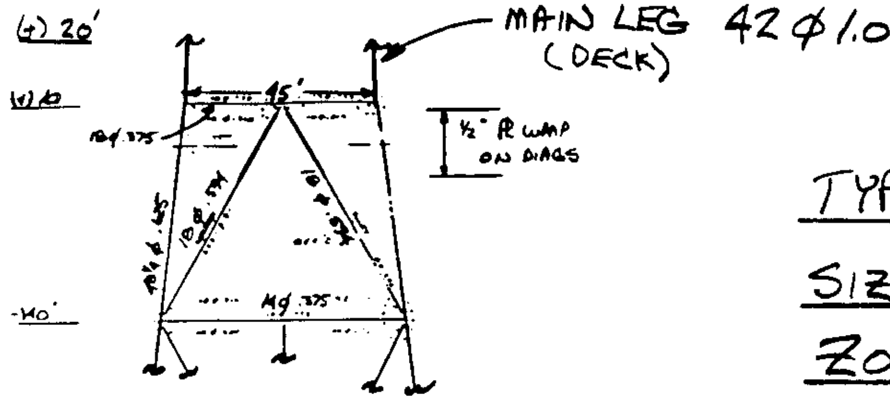
(-)X DIRECTION WAVE -200 YEAR
CHECK MEMBERS AT EL (-)40.0'

MEMBER	SECTION	AREA [FT²]	FORCE ENV (K)	STRESS, σ [KSI]	IR = σ/40 KSI
667	17	.1	-18.76	1.3	.03
668	17	.1	-10.01	.70	.02
671	7	.10124	-87.47	6.0	.13
673	5	.0675	146.76	15.1	.34
674	6	.05113	-5.72	.78	.02
675	5	.0675	-150.69	15.50	.34
682	8	.0827	15.00	1.26	.03
687	7	.10124	-58.87	4.04	.09
688	5	.0675	-93.14	9.58	.21
689	6	.05113	19.26	2.62	.06
690	5	.0675	63.99	6.58	.15
691	5	.0675	52.40	5.39	.12
692	5	.0675	-52.40	5.39	.12
693	8	.0827	61.60	5.17	.11
694	5	.0675	78.04	8.03	.18
695	5	.0675	-78.05	8.03	.18

(-)Y DIR 200 YEAR WAVE
CHECK MEMBERS AT EL (-) 40.0'

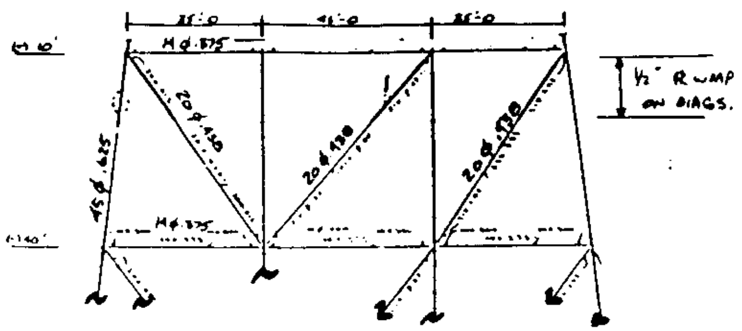
PROJECT 03B345 PAGE
BY DATE
PMB SYSTEMS ENGINEERING, INC.
SAN FRANCISCO

MEMBER	SECTION	SIZE	FORCE ENVELOPE [K]	STRESS [KSI]	IR = σ/45 KSI
667	17	.1 [FT²]	-30.77	-2.1	.05
668	17	.1	5.66	0.4	.01
671	7	.10124	10.56	0.7	.02
673	5	.0675	38.63	4.0	.09
674	6	.05113	-17.81	-2.4	.05
675	5	.0675	11.31	1.2	.03
682	8	.08270	-68.07	-5.7	.13
687	7	.10124	-12.53	-0.9	.02
688	5	.0675	-35.86	-3.7	.08
689	6	.05113	-19.32	-2.6	.06
690	5	.0675	72.55	7.5	.17
691	5	.0675	66.21	6.8	.15
692	5	.0675	-70.75	-7.3	.16
693	8	.08270	-5.36	-0.5	.01
694	5	.0675	-68.76	-7.1	.16
695	5	.0675	73.77	7.6	.17



ROWS 1-4

TYPICAL MEMBER SIZES NEAR SPLASH ZONE PRIOR TO CORROSION

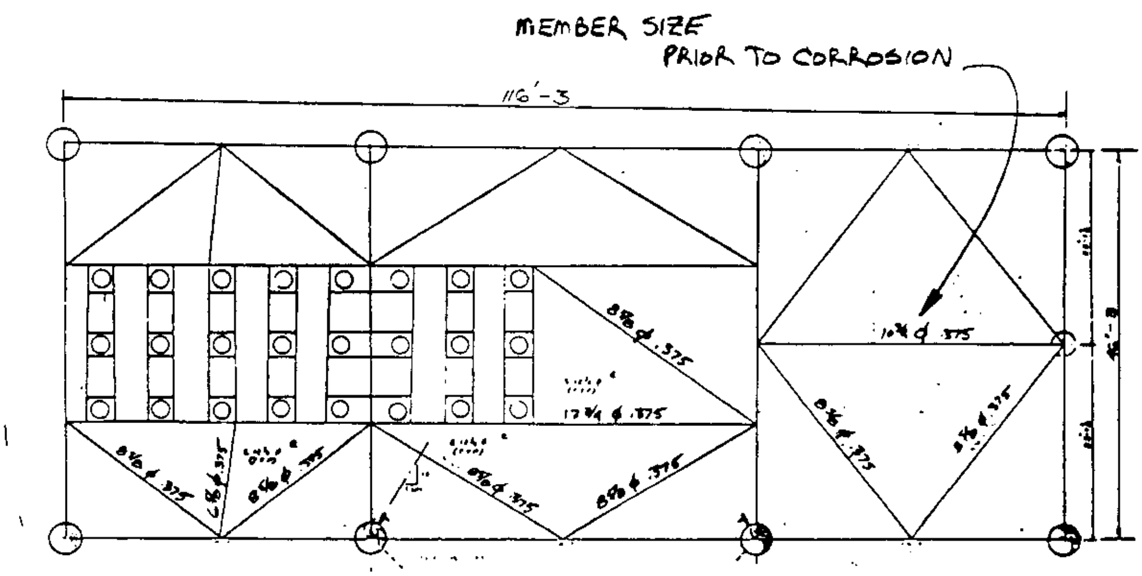


ROWS A & B

CORROSION CONDITION:

- MAIN LEGS - ¼"
- ALL OTHERS - ⅛"

REDUCTION ON THICKNESS



PLAN AT +10'

CONSEQUENCES OF GULF OF MEXICO

PLATFORM FAILURES

CAUSED BY HURRICANES

AIM III

FINAL REPORT NUMBER 2

BY

PMB SYSTEMS ENGINEERING INC.

SAN FRANCISCO, CA

SEPTEMBER 1988

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1.0 INTRODUCTION

1.1 Objectives

This report describes the activities and findings of the AIM III Project, Task No. 3, related to developing a data base of the consequences of past failures of platforms in the Gulf of Mexico. A realistic estimate of platform failure consequences is a key ingredient in the AIM approach. Methods for utilization of this consequence data is outlined in AIM III Final Report No. 3 [3] and the assessment procedures to determine the load level at which a platform may fail are outlined in AIM III Final Report Number 1 [4].

"Consequences" is defined as the sequence of events that takes place as a result of a platform failure. For example, injuries, pollution, cleanup, salvage, abandoning of wells or complete platform replacement.

The information in this report is intended to provide operators with an initial starting point in estimating the potential consequences of a platform failure and help develop the basis for AIM decisions that will be needed in the future.

1.2 Background

The scope of work for this task resulted from review of the AIM II Project [1] where two low consequence Gulf of Mexico platforms were studied to test the basic AIM approach [2]. Both the commercial cost-benefit and calibration-standard of practice approaches were used to evaluate the platforms. One of the key inputs to the approaches is the question of "what could happen if this platform should fail during a storm?" For example:

- Is there likely to be any injuries or pollution?
- Will the platform be replaced or will the wells be plugged and abandoned?
- Will there be negative public reaction or regulatory response to the incident?

During the AIM II project, an "estimating" approach was utilized to determine the potential consequences should each of the example AIM platforms loose serviceability or "fail." The "estimating" approach considered Gulf of Mexico standard practices, manning requirements, remaining service life, field economics, replacement costs and site cleanup and restoration costs. From this information, a suitable consequence of loss of serviceability scenario was drawn for each of the platforms.

For example, there was assumed to be no potential injuries since Gulf of Mexico platforms are evacuated in advance of hurricanes. In addition, the platforms were only intermittently manned. Pollution potential was low, since the platforms were producing relatively low volumes of gas and the wells contained down-hole safety valves. Site cleanup costs (platform salvage, P&A wells, etc.) were based on several contractor estimates, and were found to have a wide range. Finally, the question of platform replacement was handled by considering cases with and without replacement. Platform replacement will likely be dictated by reserves redevelopment economics.

Even though the AIM II platform consequences seemed reasonable and justifiable, several participants questioned if such consequences would occur in a "real" failure incident. Since the outcome of an AIM program is heavily dependent upon the "consequences" should a platform fail, there was a need to develop an objective data base on the consequences of past platform failures that occurred during storm loadings.

Several participants suggested an investigation and cataloguing of historical platform failures and ensuing consequences. This data would provide a reference to what might actually happened if a platform were to fail. The data could be used by participants to help define and justify potential failure consequences used in an AIM assessment.

Based upon this suggestion, a portion of the AIM III project was devoted to development of a platform failure consequences data base. The data base would summarize known consequences of platform failures caused by storms. The failures were confined to storms (extreme loading events) since these are the major types of hazards that are addressed by AIM programs.

Due to limitations in time and budget, the data base was limited to the Gulf of Mexico region. In addition, there was a desire to keep the data base congruent by limiting data to one region, thereby maintaining a consistent reference area were environmental and operating conditions are generally the same. Additional future studies may compile similar data for other offshore regions.

2.0 SCOPE OF WORK

2.1 Data Base

The general scope of work for this task was to develop a data base which catalogues historical, storm related failures and severe damage of Gulf of Mexico platforms, and reports on the known consequences of each of these incidents.

A "collapse" was defined as a complete loss of serviceability of the platform. For example, the platform is completely toppled and laying on the seafloor or is so extensively damaged that it must unquestionably be salvaged. "Severe Damage" was defined as an incident that causes significant structural damage and disruption to the platform's operation, with the platform eventually being removed from service.

Severe storm damage has also occurred on some platforms that were eventually repaired and returned to service. This damage typically consisted of "leaning" platforms, damaged topsides, damaged appurtenances (e.g. ladders, boat landings, risers) and miscellaneous damaged structural members.

Some of these "repaired" incidents were originally included in the data base; however, it was decided to restrict the data base to platforms that failed or suffered damage and were eventually removed from service due to the storm incident. This is because the types of repairs to the platforms catalogued in the data base, such as the use of a tug to straighten a single well protector, were not nearly as complicated or expensive as numerous other instances (e.g. underwater brace repair) that were not included in the data base. It was beyond the scope of this study to catalogue all storm-related repairs as well as failures. Further, since the data base was originally established to help determine consequences of platform "failures" for use in AIM evaluations, it was decided to maintain it as such and not "contaminate" the data base by including repaired damage.

The data base is confined to storm (wave, wind, current) related incidents. Several mudslide induced failures have also been included since these type of failures likely result in similar consequences as strictly a storm related failure. In addition, the mudslides were triggered by wave action during a major hurricane, so that these failures can be loosely defined as storm related. Damage from collisions, even though occurring during a storm, has not been included.

Most of the data base reflects major platforms containing 4 or more wells or containing essential operations such as quarters and control facilities. Some reports on other structures, such as such as single well tripods, have also been included where information was available.

Table 2-1 summarizes the guidelines used to develop the data base. Table 2-2 summarizes some typical types of platform failure consequences. Figure 2-1 indicates the names and locations of the offshore production regions in the Gulf of Mexico used in the data base.

2.2 Work Products

The work products for this task are summarized as follows:

1. Report summarizing approach, work activities and data base.

2. Hard copy of all data base information.

3. General findings summarized in report format.

4. Data file for a PC data base program for manipulating consequence information.

5. Reference list.

Most of this information is available within the body of this report or in the appendices. The data base information is provided in a separate floppy disk supplied to the key representative for each participant. The program is available in an R:Base or dBase format.

Where available, clear photos, figures and sketches of a failed platform are included with a description of the failure consequences. The information was selected from the reference material for this study and can be found in Appendix A.

It was an early intent to provide all of the reference material to the participants in a separate appendix; however, the volume of information became prohibitive. In addition, some of the information was supplied on a confidential basis. An extensive reference list of all the cited data contained in the data base is provided in Appendix C.

TABLE 2-1

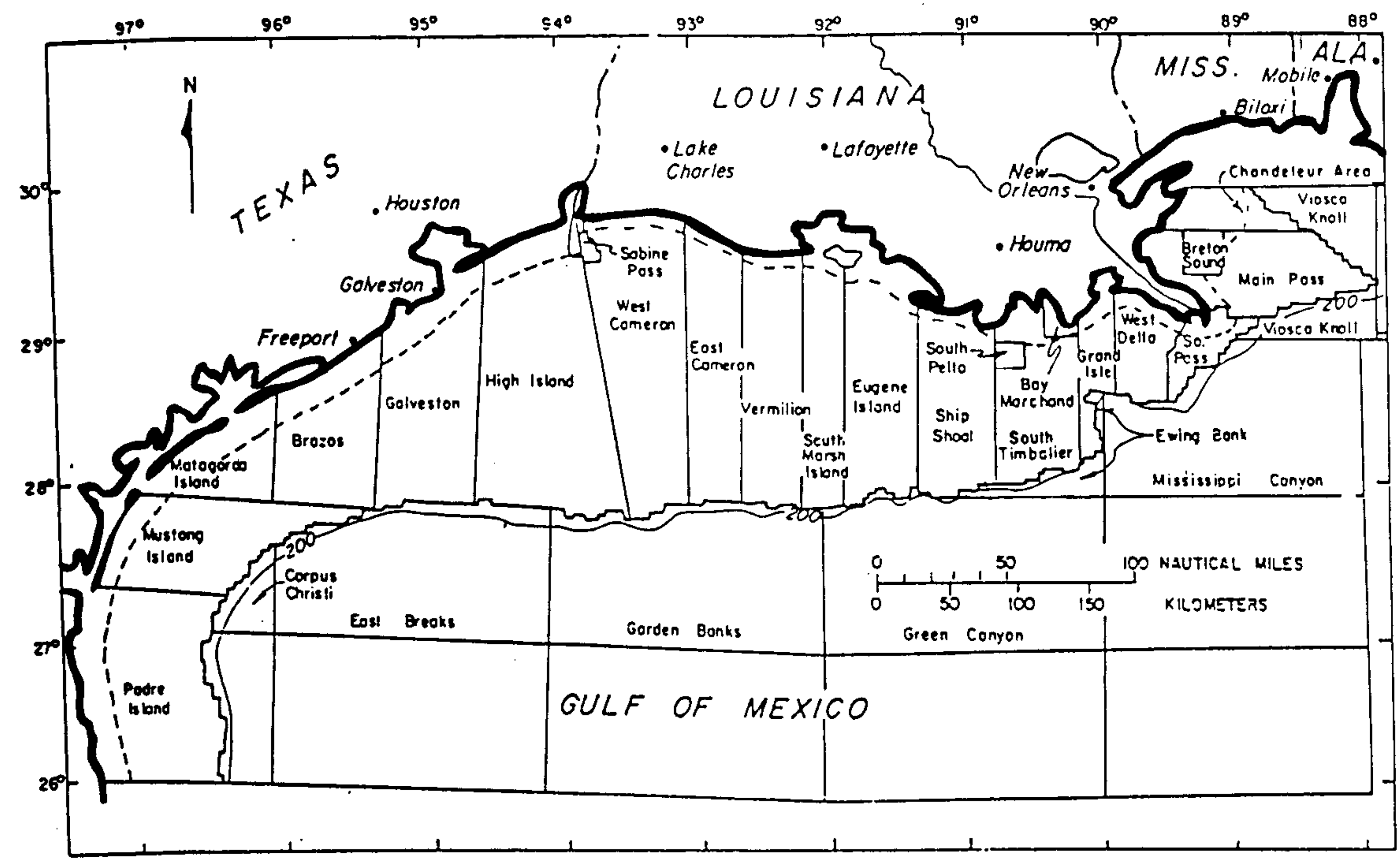
GUIDELINES FOR DEVELOPMENT OF PLATFORM FAILURES CONSEQUENCE DATA BASE

- Gulf of Mexico Locations
- Storm Related Failures. Mudslide failures have also been included.
- "Collapse" assumes a complete loss of serviceability with no nope of repair. The platform is no longer useable.
- "Severe Damage" assumes significant structural damage and disruption of platform operations. After review of the platform condition by the operator, the platform is removed from service.
- Platforms (4 or more wells, essential operations) as well as single well structures are reported.
- Period covered by the data base is 1948 thru 1988.

TABLE 2-2

TYPES OF CONSEQUENCE DATA

- Lives Lost
- Injuries
- Pollution (bbls spilled)
- Pollution Abatement Activities
- Regulatory Response
- Public Response
- Repair Operations and Costs
- Salvage Operations (Platform Removal)
- Well Plugging and Abandonment
- Lost/Delayed Production Revenues



NAMES AND LOCATIONS OF GULF OF MEXICO OFFSHORE PRODUCTION AREAS

FIGURE 2-1

3.0 PROCEDURES

3.1 Data Sources

The different types of data sources and their contribution to the final data base are summarized in the following paragraphs.

1. **Open Literature.** The public domain was extensively researched to obtain platform failure information. These sources included industry publications such as magazines and journals (Offshore, Oil and Gas Journal, etc.), conference proceedings and special reports. This data source provided the major input of information.

   The procedure began by establishing the dates of the major Gulf of Mexico hurricanes (e.g Hurricane Hilda, October 3, 1964) and then researching the literature for the timeframe of approximately one year following the storm. These data sources resulted in a substantial amount of information describing platform failures and the immediate consequences (injuries, pollution), but lacked in "longer term" definition of such data as was the platform replaced and the procedures/costs of cleanup or salvage. A subsequent review of this literature for a time frame larger than one year following a storm also failed to uncover "longer term" data.

   One deficiency of this data was the lack of credibility of some of the data sources. Some of the information was found to be conflicting. This type of unsupported data was eliminated were possible.

2. **Interviews.** Personal interviews with industry personnel participating in activities at the time of these incidents or having access to data files was attempted. This avenue was initially felt to be a promising alternative: however, after several interviews of the most promising personnel, this did not appear to be a worthwhile alternative. At the present time, there are a very few individuals still actively working int he undustry who actually partiicpated in the salvage and repair effort. Very few company records are available and unfortunately, the companies with the best records were not those that sustained major damage. Some data is probably available in personal files, but is not easy to locate or available for access. Much of the data is considered company "confidential."

   Additional contacts were made with insurance adjustors in search of some data on insurance claims related to platform failures. Again this avenue was not productive due to the confidentiality of such information.

3. **Participant Input.** Several participants provided input from data sources within their organization. This included such items as company newsletters, special investigations and reports. This provided some key credible input with explicit details not generally available in the public literature.

   All participants were provided with a set of the initial platform failures and their consequences as contained in the data base, and asked to investigate their in-house sources where possible. Unfortunately, only a limited amount of data was made available to the data base through this avenue.

4. **Private Channels.** Several private channels (lines of communication) were investigated to develop data related to platform storm induced failures. Griff C. Lee, a long time industry consultant familiar with Gulf of Mexico operations, assisted in developing the data base and seeking some additional data along personal lines. This proved to be a profitable approach and provided some key data.

5. **Existing Data Bases.** There are some existing data bases related to platform failures. The MMS maintains an accident data base related to offshore operation but most of this data is related to topsides incidents [5]. A recent set of data put together by several European agencies and known as WOAD [6], does contain some storm related accident information. The WOAD data is general in nature and does not describe complete consequence data for a specific platform or storm.

3.2 Data Review

Once the data was collected, it was sorted by platform to establish an initial list of the known failed platforms. The individual accounts and consequences associated with each platform were then compiled. The information was cross referenced where possible to check for authenticity.

A lot of the information was in general language such as "three of Conoco's platforms were lost in the hurricane." Items such as this then needed to be checked with other references to establish the location, specific platform, and any described consequences. This proved to be a time consuming task in some incidences. In some cases it proved difficult to establish more precise information from the available data.

After reviewing the type of data available, a "generic" data sheet was established (Figure 3-1) and used to input the information into a data base program, described in the following section.

3.3 Data Base Program

A PC data base program was used to store and maintain the information. Although not in the original scope of work for the project, this proved to be a useful mechanism for development of the data base. The data base will also provide an additional convenient work product for use by the participants. The use of a data base for this task was suggested by Jim Saunders of Marathon.

The data base files are formatted for use in either R:Base or dBase. Also included are data menus and operation commands to allow easy manipulation of the data base. Examples are sorting of information according to company, storm or platform location. There is also a feature so that participants can update the data base with newly acquired information. Participants are also free to add any additional features to the data base operation (provided they are knowledgeable in R:Base or dBase coding).

Appendix B contains details about the capabilities and operation of the data base program.

```
PLATFORM NAME             :
COMPANY NAME              :
STORM                     :            DATE :
DAMAGE SUMMARY            :
PLATFORM INFORMATION
  Platform Type           :
  Water Depth (ft)        :
  Number of Piles         :
  Number of Wells         :
  Install/Design Date     :
  Design Criteria         :
  Deck Elevation (ft)     :
  Original Cost           :
  Comments                :

FAILURE / CONSEQUENCES DETAILED ACCOUNTS
   Source         :
   Detailed Account:
```

EXAMPLE DATA BASE INPUT

FIGURE 3-1

4.0 GENERAL FINDINGS

4.1 Review of Findings

This subsection provides a brief description of the information contained in the data base. Sections 4.2 and 4.3 provide details of several of the data bases key information.

A total of 38 of Mexico platforms have experienced failure or severe damage due to hurricanes. The time frame covers approximately 40 years. Table 4-1 shows the name, date and number of platforms affected by each hurricane. Figure 4-1 shows the approximate storm tracks of these hurricanes.

In all of these cases there has been no known deaths or severe injuries. In terms of pollution, there has been seven known blowouts of some 140 wells releasing approximately 10,000 to 15,000 bbls of oil to the environment. In comparison, in 1970 it is estimated that approximately 16 million bbls of oil were released into the oceans due to all marine operations [7].

Some of the pollutants released into the environment by these incidents are not directly reported in the literature. Examples are spills from the sometimes large oil storage tanks (5,000 to 10,000 bbls) located on decks, drilling fluids, and other materials. In addition, there may be oil lost from damage to platform risers or pipeline connections.

The storage tanks may spill more oil than the wells. The condition of these tanks after the incident was unreported in most cases. The use of oil storage tanks on platforms is a very rare occurrence now with most oil transported to shore via pipelines. When the earlier storms occurred, there were numerous oil storage tanks on platforms with the oil being transported to shore by barge [8].

Cost information was most difficult to locate. As noted earlier, most of the information reported the physical damages, but provided little detail of the costs of repair or cleanup. In addition, cost data based upon 25-year old industry practices may not be applicable today. For example, the costs to salvage a 100 ft water depth platform in 1964 with the then available equipment, even after inflation, would likely be much different than a similar operation with today's equipment.

While compiling the data base, some interesting information turned up related to platforms that experienced severe damage but were later repaired and returned to service. As previously noted, these platforms are not included in the data base, but some important data related to these incidents is worth noting.

An Ohio quarters platform, located in what is now the Brazos or Galveston offshore areas, was severely damaged during a hurricane in 1949 (see references under 1949 "Freeport" hurricane in Appendix C). The platform was a very early generation facility with the quarters serving a nearby drilling platform. The platform's single deck had been set at an elevation of +27 ft based upon the then (1949) design for a 32-ft wave. Figure 4-2 shows a view of the platform (actually a nearby identical platform) before and after the storm. This is dramatic physical evidence of the potential for storm waves to completely wash topside facilities into the ocean. The platform was reportedly repaired and returned to service [8].

Another interesting example of severely damaged but repaired platforms are three Superior platforms damaged during hurricanes Audrey (1957) and Carla (1961). These platforms were single well protectors installed before the piles were rigidly attached to the jacket via welding or grouting. When the storm occurred, the piles slid through the legs and the jackets simply leaned over. The jackets were later straightened with the use of a tugboat [8].

In summary, based upon 40 years of experience in the Gulf of Mexico, involving 38 platform failures and some 140 wells, there have been:

A. No loss of life.

B. No severe injuries.

C. No significant pollution (10,000 to 15,000 bbl total).

D. Limited property damages (less than $50 million per event in 1988 dollars).

4.2 Platform Failures Summary

The Database Program has been used to sort the data base according to different sets of conditions related to the platform. This information is provided in the following tables:

Table 4-2 Platform Failures Sorted According to Storm

Table 4-3 Platform Failures Sorted According to Operator

Table 4-4 Platform Failures Sorted According to Location

Table 4-5 Platform Failures Sorted According to Date

4.3 Platform Failures Sorted By Consequence

The Database Program has been used to sort the data base according to different sets of consequences. Table 4-6 summarizes the number of platform failures related to different types of interesting consequences. Also included is the name and location of the platforms associated with each consequence.

TABLE 4-1

PLATFORM FAILURES CAUSED BY HURRICANES

Hurricane	Date	Platforms Affected
Grande Island	1948	2
Carla	1961	3
Hilda	1964	14
Betsy	1965	8
Camille	1969	3
Carmen	1974	2
Frederic	1979	3
Juan	1985	3
	TOTAL PLATFORMS	38

AIM FAILURE CONSEQUENCES DATABASE
DATA SORTED BY STORM

STORM	DATE	PLATFORM	COMPANY	DAMAGE
BETSY	09/09/65	W. DELTA 117-A	GULF	COLLAPSE
BETSY	09/09/65	W. DELTA 117-B	GULF	COLLAPSE
BETSY	09/09/65	W. DELTA 118	PURE	COLLAPSE
BETSY	09/09/65	W. DELTA 69 #1	CATC	COLLAPSE
BETSY	09/09/65	W. DELTA 70 #3	CATC	COLLAPSE
BETSY	09/09/65	W. DELTA 97	FORREST	COLLAPSE
BETSY	09/09/65	SOUTH PASS 24	SHELL	COLLAPSE
BETSY	09/09/65	MAIN PASS 129	PHILLIPS	COLLAPSE
CAMILLE	08/17/69	SOUTH PASS 70-A	SHELL	SEVERE DAMAGE
CAMILLE	08/17/69	SOUTH PASS 70-B	SHELL	COLLAPSE
CAMILLE	10/07/69	SOUTH PASS 61-A	GULF	COLLAPSE
CARLA	09/01/61	E. CAMERON	SHELL	SEVERE DAMAGE
CARLA	09/01/61	VERMILLION 104	ZAPATA	SEVERE DAMAGE
CARLA	09/01/61	EUGENE ISLAND 198	PLACID	SEVERE DAMAGE
CARMEN	08/07/74	SHIP SHOAL 119-F	ODECO	COLLAPSE
CARMEN	08/07/74	SHIP SHOAL 119-A	ODECO	COLLAPSE
FREDERIC	08/01/79	SOUTH PELTO 19 #11	ODECO	COLLAPSE
FREDERIC	08/01/79	SOUTH PELTO 19 #4	ODECO	COLLAPSE
FREDERIC	08/01/79	SOUTH PELTO 19 #13	ODECO	COLLAPSE
GRND ISL	09/01/48	GRANDE ISLAND 2	HUMBLE	SEVERE DAMAGE
GRND ISL	09/01/48	GRANDE ISLAND 1	HUMBLE	COLLAPSE
HILDA	10/03/64	SHIP SHOAL 199-A	TENNECO	COLLAPSE
HILDA	10/03/64	EUGENE ISLAND 208-C	CATC	COLLAPSE
HILDA	10/03/64	SHIP SHOAL 253	PURE	COLLAPSE
HILDA	10/03/64	EUGENE ISLAND 276	UNION	COLLAPSE
HILDA	10/03/64	SHIP SHOAL 154-H	GULF	COLLAPSE
HILDA	10/03/64	SHIP SHOAL 169-A	GULF	SEVERE DAMAGE
HILDA	10/03/64	EUGENE ISLAND 208-D	CATC	COLLAPSE
HILDA	10/03/64	EUGENE ISLAND 198-B	PLACID	COLLAPSE
HILDA	10/03/64	EUGENE ISLAND 208-A	CATC	COLLAPSE
HILDA	10/03/64	EUGENE ISLAND 188	SHELL	COLLAPSE
HILDA	10/03/64	SHIP SHOAL 149-B	SIGNAL	COLLAPSE
HILDA	10/03/64	SHIP SHOAL 154-B	GULF	COLLAPSE
HILDA	10/03/64	EUGENE ISLAND 175-A	SINCLAIR	COLLAPSE
HILDA	10/03/64	SHIP SHOAL 198-C	TENNECO	COLLAPSE
JUAN	10/27/85	SOUTH PELTO 19 SWP	ODECO	COLLAPSE
JUAN	09/27/85	S. TIMBALIER 86 PL.A	ODECO	COLLAPSE
JUAN	10/27/85	SOUTH PELTO 19 OBM	ODECO	COLLAPSE

PLATFORM FAILURES SORTED ACCORDING TO STORM

TABLE 4-2

AIM FAILURE CONSEQUENCES DATABASE
DATA SORTED BY COMPANY

COMPANY	PLATFORM	STORM	DATE	DAMAGE
CATC	W. DELTA 70 #3	BETSY	09/09/65	COLLAPSE
CATC	EUGENE ISLAND 208-A	HILDA	10/03/64	COLLAPSE
CATC	EUGENE ISLAND 208-C	HILDA	10/03/64	COLLAPSE
CATC	W. DELTA 69 #1	BETSY	09/09/65	COLLAPSE
CATC	EUGENE ISLAND 208-D	HILDA	10/03/64	COLLAPSE
FORREST	W. DELTA 97	BETSY	09/09/65	COLLAPSE
GULF	W. DELTA 117-A	BETSY	09/09/65	COLLAPSE
GULF	SHIP SHOAL 169-A	HILDA	10/03/64	SEVERE DAMAGE
GULF	SHIP SHOAL 154-B	HILDA	10/03/64	COLLAPSE
GULF	W. DELTA 117-B	BETSY	09/09/65	COLLAPSE
GULF	SOUTH PASS 61-A	CAMILLE	10/07/69	COLLAPSE
GULF	SHIP SHOAL 154-H	HILDA	10/03/64	COLLAPSE
HUMBLE	GRANDE ISLAND 2	GRND ISL	09/01/48	SEVERE DAMAGE
HUMBLE	GRANDE ISLAND 1	GRND ISL	09/01/48	COLLAPSE
ODECO	S. TIMBALIER 86 PL.A	JUAN	09/27/85	COLLAPSE
ODECO	SHIP SHOAL 119-F	CARMEN	08/07/74	COLLAPSE
ODECO	SOUTH PELTO 19 #4	FREDERIC	08/01/79	COLLAPSE
ODECO	SOUTH PELTO 19 #13	FREDERIC	08/01/79	COLLAPSE
ODECO	SOUTH PELTO 19 #11	FREDERIC	08/01/79	COLLAPSE
ODECO	SHIP SHOAL 119-A	CARMEN	08/07/74	COLLAPSE
ODECO	SOUTH PELTO 19 SWP	JUAN	10/27/85	COLLAPSE
ODECO	SOUTH PELTO 19 OBM	JUAN	10/27/85	COLLAPSE
PHILLIPS	MAIN PASS 129	BETSY	09/09/65	COLLAPSE
PLACID	EUGENE ISLAND 198-B	HILDA	10/03/64	COLLAPSE
PLACID	EUGENE ISLAND 198	CARLA	09/01/61	SEVERE DAMAGE
PURE	W. DELTA 118	BETSY	09/09/65	COLLAPSE
PURE	SHIP SHOAL 253	HILDA	10/03/64	COLLAPSE
SHELL	SOUTH PASS 70-A	CAMILLE	08/17/69	SEVERE DAMAGE
SHELL	E. CAMERON	CARLA	09/01/61	SEVERE DAMAGE
SHELL	SOUTH PASS 70-B	CAMILLE	08/17/69	COLLAPSE
SHELL	SOUTH PASS 24	BETSY	09/09/65	COLLAPSE
SHELL	EUGENE ISLAND 188	HILDA	10/03/64	COLLAPSE
SIGNAL	SHIP SHOAL 149-B	HILDA	10/03/64	COLLAPSE
SINCLAIR	EUGENE ISLAND 175-A	HILDA	10/03/64	COLLAPSE
TENNECO	SHIP SHOAL 199-A	HILDA	10/03/64	COLLAPSE
TENNECO	SHIP SHOAL 198-C	HILDA	10/03/64	COLLAPSE
UNION	EUGENE ISLAND 276	HILDA	10/03/64	COLLAPSE
ZAPATA	VERMILLION 104	CARLA	09/01/61	SEVERE DAMAGE

PLATFORM FAILURES SORTED ACCORDING TO OPERATOR

TABLE 4-3

AIM FAILURE CONSEQUENCES DATABASE
DATA SORTED BY PLATFORM/LOCATION

PLATFORM	COMPANY	STORM	DATE	DAMAGE
E. CAMERON	SHELL	CARLA	09/01/61	SEVERE DAMAGE
EUGENE ISLAND 175-A	SINCLAIR	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 188	SHELL	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 198	PLACID	CARLA	09/01/61	SEVERE DAMAGE
EUGENE ISLAND 198-B	PLACID	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 208-A	CATC	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 208-C	CATC	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 208-D	CATC	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 276	UNION	HILDA	10/03/64	COLLAPSE
GRANDE ISLAND 1	HUMBLE	GRND ISL	09/01/48	COLLAPSE
GRANDE ISLAND 2	HUMBLE	GRND ISL	09/01/48	SEVERE DAMAGE
MAIN PASS 129	PHILLIPS	BETSY	09/09/65	COLLAPSE
S. TIMBALIER 86 PL.A	ODECO	JUAN	09/27/85	COLLAPSE
SHIP SHOAL 119-A	ODECO	CARMEN	08/07/74	COLLAPSE
SHIP SHOAL 119-F	ODECO	CARMEN	08/07/74	COLLAPSE
SHIP SHOAL 149-B	SIGNAL	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 154-B	GULF	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 154-H	GULF	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 169-A	GULF	HILDA	10/03/64	SEVERE DAMAGE
SHIP SHOAL 198-C	TENNECO	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 199-A	TENNECO	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 253	PURE	HILDA	10/03/64	COLLAPSE
SOUTH PASS 24	SHELL	BETSY	09/09/65	COLLAPSE
SOUTH PASS 61-A	GULF	CAMILLE	10/07/69	COLLAPSE
SOUTH PASS 70-A	SHELL	CAMILLE	08/17/69	SEVERE DAMAGE
SOUTH PASS 70-B	SHELL	CAMILLE	08/17/69	COLLAPSE
SOUTH PELTO 19 #11	ODECO	FREDERIC	08/01/79	COLLAPSE
SOUTH PELTO 19 #13	ODECO	FREDERIC	08/01/79	COLLAPSE
SOUTH PELTO 19 #4	ODECO	FREDERIC	08/01/79	COLLAPSE
SOUTH PELTO 19 OBM	ODECO	JUAN	10/27/85	COLLAPSE
SOUTH PELTO 19 SWP	ODECO	JUAN	10/27/85	COLLAPSE
VERMILLION 104	ZAPATA	CARLA	09/01/61	SEVERE DAMAGE
W. DELTA 117-A	GULF	BETSY	09/09/65	COLLAPSE
W. DELTA 117-B	GULF	BETSY	09/09/65	COLLAPSE
W. DELTA 118	PURE	BETSY	09/09/65	COLLAPSE
W. DELTA 69 #1	CATC	BETSY	09/09/65	COLLAPSE
W. DELTA 70 #3	CATC	BETSY	09/09/65	COLLAPSE
W. DELTA 97	FORREST	BETSY	09/09/65	COLLAPSE

PLATFORM FAILURES SORTED ACCORDING TO LOCATION

TABLE 4-4

AIM FAILURE CONSEQUENCES DATABASE
DATA SORTED BY DATE

DATE	STORM	PLATFORM	COMPANY	DAMAGE
09/01/48	GRND ISL	GRANDE ISLAND 2	HUMBLE	SEVERE DAMAGE
09/01/48	GRND ISL	GRANDE ISLAND 1	HUMBLE	COLLAPSE
09/01/61	CARLA	E. CAMERON	SHELL	SEVERE DAMAGE
09/01/61	CARLA	EUGENE ISLAND 198	PLACID	SEVERE DAMAGE
09/01/61	CARLA	VERMILLION 104	ZAPATA	SEVERE DAMAGE
10/03/64	HILDA	EUGENE ISLAND 198-B	PLACID	COLLAPSE
10/03/64	HILDA	EUGENE ISLAND 208-C	CATC	COLLAPSE
10/03/64	HILDA	EUGENE ISLAND 208-A	CATC	COLLAPSE
10/03/64	HILDA	EUGENE ISLAND 276	UNION	COLLAPSE
10/03/64	HILDA	EUGENE ISLAND 175-A	SINCLAIR	COLLAPSE
10/03/64	HILDA	EUGENE ISLAND 188	SHELL	COLLAPSE
10/03/64	HILDA	SHIP SHOAL 198-C	TENNECO	COLLAPSE
10/03/64	HILDA	SHIP SHOAL 199-A	TENNECO	COLLAPSE
10/03/64	HILDA	SHIP SHOAL 253	PURE	COLLAPSE
10/03/64	HILDA	SHIP SHOAL 169-A	GULF	SEVERE DAMAGE
10/03/64	HILDA	EUGENE ISLAND 208-D	CATC	COLLAPSE
10/03/64	HILDA	SHIP SHOAL 154-B	GULF	COLLAPSE
10/03/64	HILDA	SHIP SHOAL 154-H	GULF	COLLAPSE
10/03/64	HILDA	SHIP SHOAL 149-B	SIGNAL	COLLAPSE
09/09/65	BETSY	SOUTH PASS 24	SHELL	COLLAPSE
09/09/65	BETSY	W. DELTA 70 #3	CATC	COLLAPSE
09/09/65	BETSY	W. DELTA 97	FORREST	COLLAPSE
09/09/65	BETSY	W. DELTA 118	PURE	COLLAPSE
09/09/65	BETSY	MAIN PASS 129	PHILLIPS	COLLAPSE
09/09/65	BETSY	W. DELTA 117-A	GULF	COLLAPSE
09/09/65	BETSY	W. DELTA 117-B	GULF	COLLAPSE
09/09/65	BETSY	W. DELTA 69 #1	CATC	COLLAPSE
08/17/69	CAMILLE	SOUTH PASS 70-A	SHELL	SEVERE DAMAGE
08/17/69	CAMILLE	SOUTH PASS 70-B	SHELL	COLLAPSE
10/07/69	CAMILLE	SOUTH PASS 61-A	GULF	COLLAPSE
08/07/74	CARMEN	SHIP SHOAL 119-F	ODECO	COLLAPSE
08/07/74	CARMEN	SHIP SHOAL 119-A	ODECO	COLLAPSE
08/01/79	FREDERIC	SOUTH PELTO 19 #11	ODECO	COLLAPSE
08/01/79	FREDERIC	SOUTH PELTO 19 #4	ODECO	COLLAPSE
08/01/79	FREDERIC	SOUTH PELTO 19 #13	ODECO	COLLAPSE
09/27/85	JUAN	S. TIMBALIER 86 PL.A	ODECO	COLLAPSE
10/27/85	JUAN	SOUTH PELTO 19 SWP	ODECO	COLLAPSE
10/27/85	JUAN	SOUTH PELTO 19 OBM	ODECO	COLLAPSE

PLATFORM FAILURES SORTED ACCORDING TO DATE

TABLE 4-5

CONSEQUENCES ASSOCIATED WITH KEYWORD "BLOWOUT"

PLATFORM	STORM	CONSEQUENCE DETAIL WITH KEYWORD
EUGENE ISLAND 175-A	HILDA	ONE HIGH PRESSURE WELL LEAKING BADLY AND ONE BLOWOUT IN THE 7"-9 5/8" CASING ANNULUS.
EUGENE ISLAND 208-A	HILDA	BLOWOUT, 5180 BBLS SPILLED, BETWEEN PLATFORMS 208-A,C,&D, GAS AND OIL, SPREAD OVER SEVERAL DAYS. WELLS EVENTUALLY CEMENTED. NO RECORDED ENVIRONMENTAL DAMAGE.
EUGENE ISLAND 208-C	HILDA	BLOWOUT, 5100 BBLS SPILLED, BETWEEN PLATFORMS A, C & D, GAS AND OIL, OVER SEVERAL DAYS. WELLS EVENTUALLY CEMENTED. NO RECORDED ENVIRONMENTAL DAMAGE.
EUGENE ISLAND 208-D	HILDA	BLOWOUT, 5100 BBLS SPILLED, BETWEEN PLATFORMS 208-A, C, & D, GAS AND OIL, OVER SEVERAL DAYS. WELLS EVENTUALLY CEMENTED. NO RECORDED ENVIRONMENTAL DAMAGE.
SHIP SHOAL 154-B	HILDA	GAS BLOWOUT. 15 DAYS. CONTROLLED BY BRIDGING.
SHIP SHOAL 154-H	HILDA	APPARENTLY NO BLOWOUTS OR SPILLS.
W. DELTA 117-A	BETSY	OIL BLOWOUT, CEMENTED. MINIMAL SPILL VOLUME.
W. DELTA 117-B	BETSY	APPARENTLY NO BLOWOUTS OR SPILLS.

PLATFORM FAILURES SORTED ACCORDING TO CONSEQUENCE

TABLE 4-6

CONSEQUENCES ASSOCIATED WITH KEYWORD "SALVAGE"

PLATFORM	STORM	CONSEQUENCE DETAIL WITH KEYWORD
EUGENE ISLAND 188	HILDA	PLATFORM WAS SALVAGED AND INVESTIGATED. BRACES APPEARED TO BE PULLED OUT OF LEGS IN A "COUPON" FAILURE MODE. INVESTIGATORS BELIEVE THIS INDICATED JOINT FAILURE.
EUGENE ISLAND 198-B	HILDA	PLATFORM WAS SALVAGED AND REPLACED -- NEW JACKET WITH OLD DECK, RAISED TO +50 FEET. JACKET WAS REBUILT AND USED AT NEW LOCATION AT A LATER DATE.
EUGENE ISLAND 208-A	HILDA	PLATFORM SALVAGED FOR JUNK BY BROWN AND ROOT. CATC EXPECTS TO REDRILL SOME OR ALL WELLS.
EUGENE ISLAND 208-C	HILDA	PLATFORM SALVAGED FOR JUNK BY BROWN AND ROOT. CATC EXPECTS TO REDRILL ALL OR SOME WELLS.
EUGENE ISLAND 208-D	HILDA	SALVAGED FOR JUNK BY BROWN & ROOT. ONE WELL BUBBLED GAS. CATC EXPECTS TO REDRILL ALL OR SOME WELLS.
SHIP SHOAL 154-B	HILDA	NO OIL SPILLED. PLATFORM SALVAGED.
SHIP SHOAL 199-A	HILDA	QUESTIONABLE IF PLATFORM CAN BE SALVAGED.
SOUTH PASS 61-A	CAMILLE	COSTS & DURATIONS (ESTIMATED) 1970: FOR P&A OF 16 WELLS (14 COMPLETIONS)--$1.5 MIL, 50 DAYS; FOR PLATFORM SALVAGE & DISPOSAL --$2.5 MIL, 75 DAYS; FOR A TOTAL OF $3.5 MIL, 125 DAYS.
SOUTH PASS 61-A	CAMILLE	"HIGH SEAS" NEW WORKOVER RIG SANK WITH PLATFORM. PLATFORM HAD BEEN INSTALLED PREVIOUS YEAR. RIG WAS POSSIBLY SALVAGED.
SOUTH PASS 70-A	CAMILLE	PLATFORM WAS PUSHED DOWNSLOPE SOME 4 TO 5 FEET AT ITS BASE. IT REMAINED STANDING. DRILLING OPERATIONS RESUMED; DRILLING DIFFICULTIES AROSE DUE TO THE DAMAGE (DISPLACED BOTTOM) AND THE PLATFORM WAS EVENTUALLY SALVAGED.
SOUTH PASS 70-B	CAMILLE	PLATFORM WAS EVENTUALLY CUT UP AND SALVAGED.
W. DELTA 117-A	BETSY	SALVAGE WORK REQUIRED MANY DIVERS IN DECOMPRESSION. P&A PLUS SALVAGE TOOK 55 DAYS. THIS INCLUDES 8 DAYS LOST TO WEATHER. SURFACE DIVERS USED FOR 20 DAYS; DECOMPRESSION USED FOR 33 DAYS. THE PLATFORM PIECES WERE SALVAGED AS JUNK.
W. DELTA 117-B	BETSY	WELLS WERE P&A'D AND CUT DOWN TO M.L. IN 44 DAYS. THE PLATFORM WAS EVENTUALLY CUT UP AND SALVAGED FOR JUNK.

PLATFORM FAILURES SORTED ACCORDING TO CONSEQUENCE

TABLE 4-6
(CONTINUED)

CONSEQUENCES ASSOCIATED WITH KEYWORD "RIG"

PLATFORM	STORM	CONSEQUENCE DETAIL WITH KEYWORD
EUGENE ISLAND 208-A	HILDA	JACKET WAS PREVIOUSLY DAMAGED BY COLLISION AND HAD NOT YET BEEN REPAIRED AT THE TIME OF THE STORM. THIS PLATFORM WAS NOT AT ITS ORIGINAL DESIGN STRENGTH.
EUGENE ISLAND 276	HILDA	BREWSTER-BARTLE RIG LOST WITH PLATFORM WAS WORTH MORE THAN $1 MILLION. DRILLER WAS ON THIRD WELL WHEN STORM STRUCK.
SHIP SHOAL 253	HILDA	JACKET FAILED -60'TO -80'. DECK ON TO OF RIG ON WEST SIDE.
SHIP SHOAL 253	HILDA	A NEW FALCON SEABOARD RIG LOST WITH PLATFORM WAS WORTH $1.7 MILLION. RIG WAS DRILLING FIRST WELL WHEN SHUT DOWN FOR STORM.
SOUTH PASS 61-A	CAMILLE	HIGH SEAS RIG LOSS IS ESTIMATED AT $1 MILLION.
SOUTH PASS 61-A	CAMILLE	"HIGH SEAS" NEW WORKOVER RIG SANK WITH PLATFORM. PLATFORM HAD BEEN INSTALLED PREVIOUS YEAR. RIG WAS POSSIBLY SALVAGED.
SOUTH PASS 61-A	CAMILLE	GULF REPORTEDLY HAD A $5 MILLION DEDUCTIBLE INSURANCE POLICY COVERING ITS MARINE FACILITIES IN THE AREA. RIG WAS ALSO COVERED BY INSURANCE.

PLATFORM FAILURES SORTED ACCORDING TO CONSEQUENCE

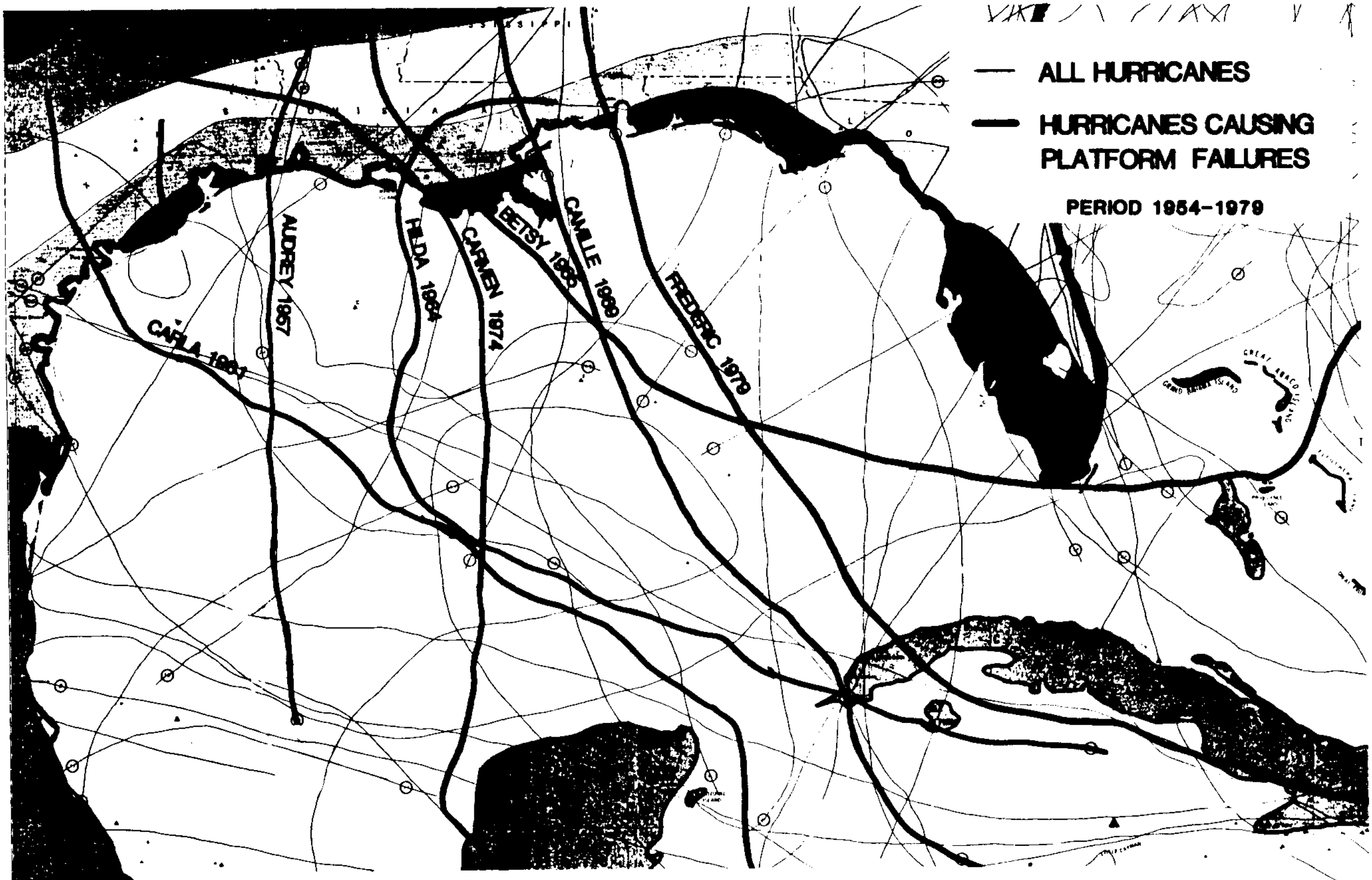
TABLE 4-6
(CONTINUED)

CONSEQUENCES ASSOCIATED WITH KEYWORD "BBL"(SPILL VOLUME)

PLATFORM	STORM	CONSEQUENCE DETAIL WITH KEYWORD
EUGENE ISLAND 175-A	HILDA	CONTAINED QUARTERS BUILDING AND 5 STORAGE TANKS TOTALING 17,000 BBLS. 4 COMPLETED OIL WELLS. 3500 BBLS ON BOARD AT TIME OF COLLAPSE.
EUGENE ISLAND 208-A	HILDA	BLOWOUT, 5180 BBLS SPILLED, BETWEEN PLATFORMS 208-A,C,&D, GAS AND OIL, SPREAD OVER SEVERAL DAYS. WELLS EVENTUALLY CEMENTED. NO RECORDED ENVIRONMENTAL DAMAGE.
EUGENE ISLAND 208-C	HILDA	BLOWOUT, 5100 BBLS SPILLED, BETWEEN PLATFORMS A, C & D, GAS AND OIL, OVER SEVERAL DAYS. WELLS EVENTUALLY CEMENTED. NO RECORDED ENVIRONMENTAL DAMAGE.
EUGENE ISLAND 208-D	HILDA	SALVAGED FOR JUNK BY BROWN & ROOT. ONE WELL BUBBLED GAS. CATC EXPECTS TO REDRILL ALL OR SOME WELLS.
EUGENE ISLAND 208-D	HILDA	BLOWOUT, 5100 BBLS SPILLED, BETWEEN PLATFORMS 208-A, C, & D, GAS AND OIL, OVER SEVERAL DAYS. WELLS EVENTUALLY CEMENTED. NO RECORDED ENVIRONMENTAL DAMAGE.
SHIP SHOAL 149-B	HILDA	5100 BBLS LOST FROM TANK.
SHIP SHOAL 149-B	HILDA	LOSS OF THIS STORAGE FACILITY CAUSED SIGNAL TO SHUT-IN ABOUT 650 BBL/DAY FROM ELSEWHERE.
W. DELTA 117-A	BETSY	MINOR SPILL (LESS THAN 238 BBL).

PLATFORM FAILURES SORTED ACCORDING TO CONSEQUENCE

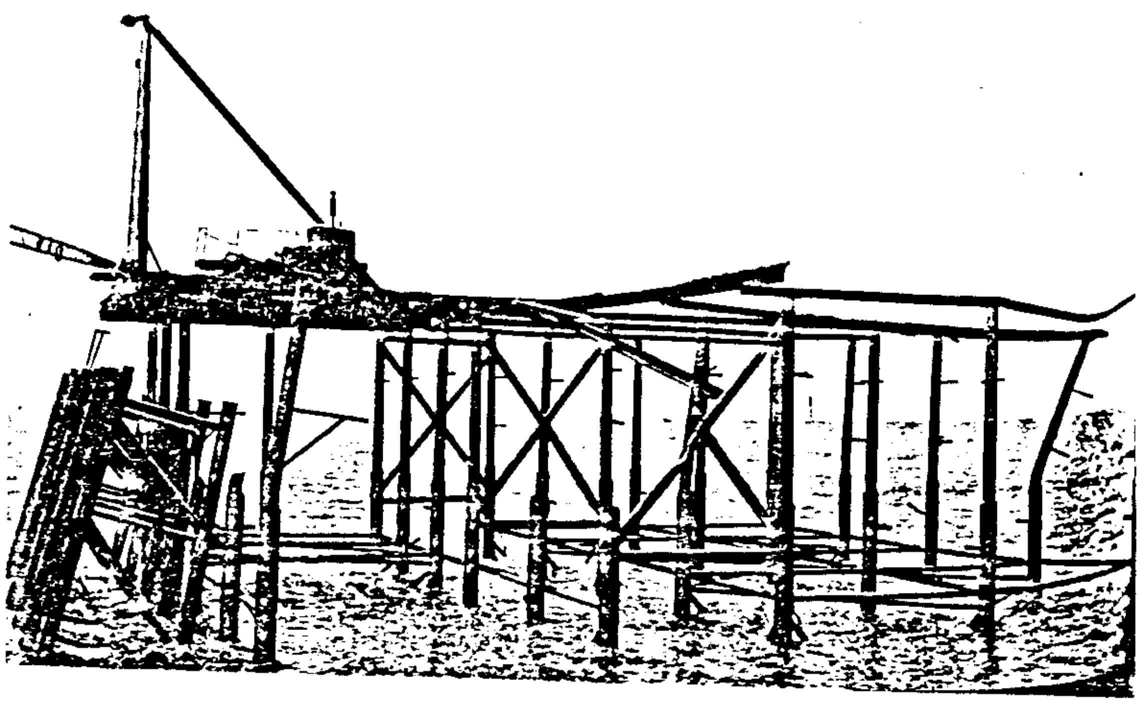
TABLE 4-6
(CONTINUED)



STORM TRACKS OF HURRICANES CAUSING PLATFORM FAILURES

F JRE 4-1

This photo is of the quarters platform at The Ohio's first offshore test. This platform is almost identical to the one swept by the hurricane. Principal difference was the placing of a stiff leg derrick on the second platform instead of a fuel tank as on the first.



In sharp contrast to the photo above is this view of the quarters platform after the storm had stripped it of the 65 x 30 x 13 foot high, 85 ton bunk house and the 40 x 19 x 13 foot, 35 ton galley. The dolphin was tilted into the structure, the ladders and walkaways ripped away, and the 8-inch I-beams twisted. Note the 10¾-inch pile bent at a point just above the weld to the 14-inch O. D. jacket. Damage to the stiff leg derrick and engine was negligible.

EXAMPLE ILLUSTRATION OF THE EFFECT OF WAVES ON DECK EQUIPMENT

FIGURE 4-2

5.0 CONCLUSIONS

This task of the AIM III project has resulted in compilation of a data base reporting the consequences of historical storm related platform failures in the Gulf of Mexico. The time frame covered by the data base is approximately 40 years involving 38 platform failures.

The intent of the data base was to provide a source of information so that participants may have a starting point for determining the potential consequences should a particular platform fail. The extent of these consequences are an important input to the AIM process.

The collected information indicates there has been no catastrophic incidents due to storm related platform failures. There has been some minor pollution, but no deaths or widespread environmental damage. However, this does not mean that these should be eliminated form consideration since most of the failed platforms were of the "low consequence" type - often unmanned with gas or nonflowing wells.

Long term action items, such as platform replacement and salvage operations are generally lacking from the data base. However, these items will likely be based on company policy and field economics rather than on historical precedence. The question of platform replacement will likely be determined by an economics group rather than the structural engineering group.

Initial plans for this task included investigation of the costs incurred by the operator due to a platform failure that might be included in current AIM evaluations; however, the historical cost of clean up, salvage, replacement and/or repairs does not necessarily have a direct bearing on an AIM decision that will be needed in the future. Instead, it is suggested that the information developed in this report be utilized to assist in predicting the consequence and that all cost information be estimated based upon projected industry conditions at that time.

The information that was collected has been provided in an easy-to-use data base format for use with a data base program. Information can be sorted quickly and accurately with this capability. A hardcopy print of much of the more useful data, sorted according to key items, is provided throughout this document.

The compiled data base provides an initial starting point for estimating consequences; however, the data base is not as detailed as originally anticipated. There appears to be a lack of detailed information concerning these failures and the actions taken by companies to remedy the problem. This may be due to the lack of "active " files (files may exist but cannot be located), reluctance to provide such information due to confidential concerns or perhaps the general lack of adequate documentation of actions taken after such incidents. More information may exist, but is beyond the limitations of this study to obtain.

Several participants noted throughout this study that the lack of this data in an easily accessible format indicates there is a need to better document this type of information. Better documentation of these incidents would have resulted in a more useful piece of information that could today be used for better planning of AIM programs for platforms.

REPORT REFERENCES

This reference list summarizes references cited in the body of this report. Appendix C contains a separate reference list, itemizing sources for the platform failures data base.

1. PMB Systems Engineering, Inc., "Development of Platform AIM (Assessment, Inspection, Maintenance) Programs," Phase II Report to Joint Industry Project, October 1987.

2. PMB Systems Engineering, Inc., "Development of Inspection and Repair Programs for Fixed Offshore Platforms," Report to Technology Assessment and Research Branch, Minerals Management Service, June 1987.

3. PMB Systems Engineering, Inc., "Development of Guidelines for Evaluation and Justifications of Suitability for Service," AIM III Final Report to Joint Industry Project, September 1988.

4. PMB Systems Engineering, Inc., "Platform 'C' Intact and Damage Condition Assessments," AIM III Final Report to Joint Industry Project, September 1988.

5. Minerals Management Service (MMS), "Accidents Connected with Federal Oil and Gas Operations on the Gulf of Mexico Outer Continental Shelf, Volume 1, 1956-1979," Report No. MMS86-0039, May 1986.

6. Veritec, "World-Wide Offshore Accident Databank," WOAD 85, Oslo Norway, 1985.

7. Kash, Don E., "A Technology Assessment of Outer Continental Shelf Oil and Gas Operations, Appendix B: Oil Pollution and Accidents," University of Oklahoma, 1973.

8. Lee, Griff, C., Miscellaneous Correspondence with PMB regarding AIM III Platform Failures Data Base.

APPENDIX A

INDIVIDUAL CASE HISTORIES AND PICTORIAL DESCRIPTIONS

The data is sorted by platform, in alphabetical order.

Where possible, clear photographs, figures and sketches of a failed platform are included with a description of the failure consequences.

AIM FAILURE CONSEQUENCES DATABASE
DATA SORTED BY PLATFORM/LOCATION

PLATFORM	COMPANY	STORM	DATE	DAMAGE
E. CAMERON	SHELL	CARLA	09/01/61	SEVERE DAMAGE
EUGENE ISLAND 175-A	SINCLAIR	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 188	SHELL	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 198	PLACID	CARLA	09/01/61	SEVERE DAMAGE
EUGENE ISLAND 198-B	PLACID	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 208-A	CATC	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 208-C	CATC	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 208-D	CATC	HILDA	10/03/64	COLLAPSE
EUGENE ISLAND 276	UNION	HILDA	10/03/64	COLLAPSE
* GRANDE ISLAND 1	HUMBLE	GRND ISL	09/01/48	COLLAPSE
* GRANDE ISLAND 2	HUMBLE	GRND ISL	09/01/48	SEVERE DAMAGE
MAIN PASS 129	PHILLIPS	BETSY	09/09/65	COLLAPSE
S. TIMBALIER 86 PL.A	ODECO	JUAN	09/27/85	COLLAPSE
SHIP SHOAL 119-A	ODECO	CARMEN	08/07/74	COLLAPSE
SHIP SHOAL 119-F	ODECO	CARMEN	08/07/74	COLLAPSE
SHIP SHOAL 149-B	SIGNAL	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 154-B	GULF	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 154-H	GULF	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 169-A	GULF	HILDA	10/03/64	SEVERE DAMAGE
SHIP SHOAL 198-C	TENNECO	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 199-A	TENNECO	HILDA	10/03/64	COLLAPSE
SHIP SHOAL 253	PURE	HILDA	10/03/64	COLLAPSE
SOUTH PASS 24	SHELL	BETSY	09/09/65	COLLAPSE
SOUTH PASS 61-A	GULF	CAMILLE	10/07/69	COLLAPSE
SOUTH PASS 70-A	SHELL	CAMILLE	08/17/69	SEVERE DAMAGE
SOUTH PASS 70-B	SHELL	CAMILLE	08/17/69	COLLAPSE
SOUTH PELTO 19 #11	ODECO	FREDERIC	08/01/79	COLLAPSE
SOUTH PELTO 19 #13	ODECO	FREDERIC	08/01/79	COLLAPSE
SOUTH PELTO 19 #4	ODECO	FREDERIC	08/01/79	COLLAPSE
SOUTH PELTO 19 OBM	ODECO	JUAN	10/27/85	COLLAPSE
SOUTH PELTO 19 SWP	ODECO	JUAN	10/27/85	COLLAPSE
VERMILLION 104	ZAPATA	CARLA	09/01/61	SEVERE DAMAGE
W. DELTA 117-A	GULF	BETSY	09/09/65	COLLAPSE
W. DELTA 117-B	GULF	BETSY	09/09/65	COLLAPSE
W. DELTA 118	PURE	BETSY	09/09/65	COLLAPSE
W. DELTA 69 #1	CATC	BETSY	09/09/65	COLLAPSE
W. DELTA 70 #3	CATC	BETSY	09/09/65	COLLAPSE
W. DELTA 97	FORREST	BETSY	09/09/65	COLLAPSE

* Tem.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:49:17

PLATFORM NAME : E. CAMERON
COMPANY NAME : SHELL

STORM : CARLA DATE : 09/01/61

DAMAGE SUMMARY : SEVERE DAMAGE

PLATFORM INFORMATION

Platform Type : WELL PROTECTOR
Water Depth (ft) :
Number of Piles : 4
Number of Wells :
Install\Design Date :
Design Criteria :
Deck Elevation (ft) :
Original Plat. Cost :
Comments :

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1981	STRUCTURE LEANING. PILE "PULLOUT."

---------------- AIM Failure Consequences Database -------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 10:29:36

PLATFORM NAME : EUGENE ISLAND 175-A
COMPANY NAME : SINCLAIR

STORM : HILDA DATE : 10/03/64

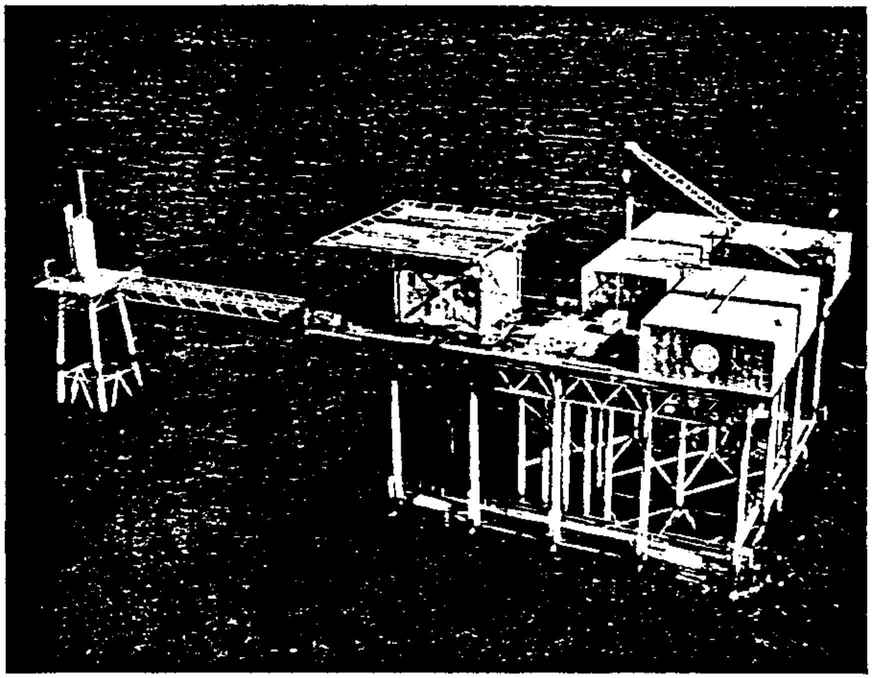
DAMAGE SUMMARY : COLLAPSE

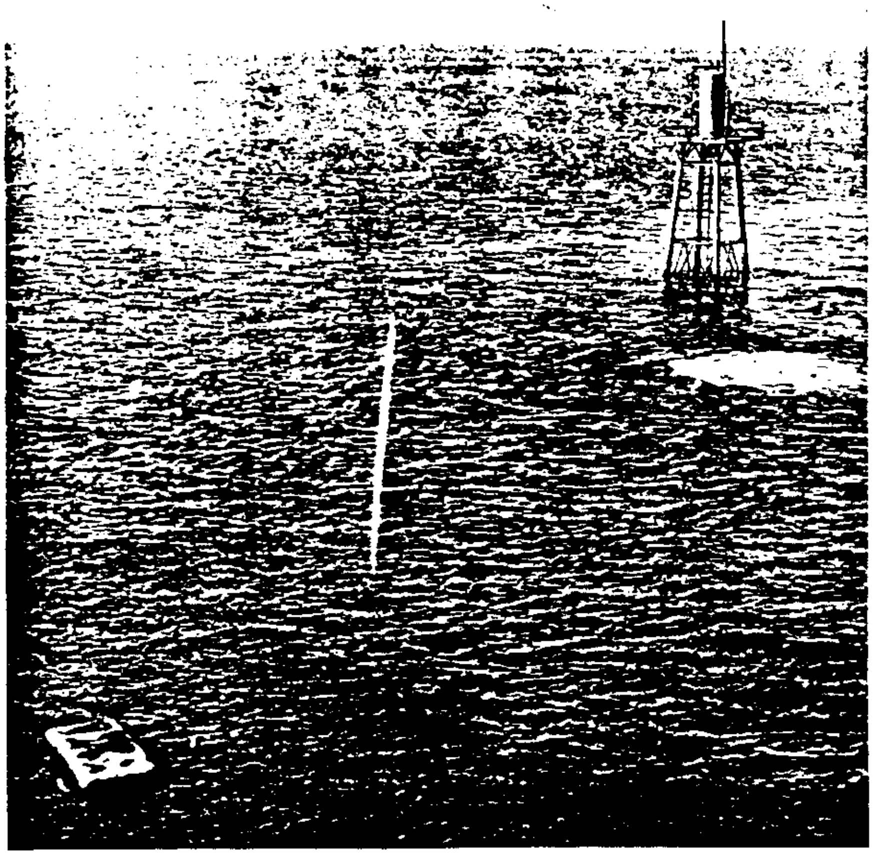
PLATFORM INFORMATION

Platform Type : SELF-CONTAINED
Water Depth (ft) : 87
Number of Piles : 16
Number of Wells : 4
Install\Design Date : 01/07/55
Design Criteria : 25 YEAR
Deck Elevation (ft) : 51
Original Plat. Cost :
Comments : ONE 10 PILE AND ONE 6 PILE JACKET. CONTAINED WELLS, QUARTERS & STORAGE TANKS.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
HILDA CONF. 1964	ONE HIGH PRESSURE WELL LEAKING BADLY AND ONE BLOWOUT IN THE 7"-9 5/8" CASING ANNULUS.
OGJ, 11/9/64	WHAT IS LEFT OF WELLS STANDS ABOUT 10 FT OFF MUD & MUST EVENTUALLY BE CUT OFF AT MUDLINE.
HILDA CONF. 1964	LEAKING WELLS WERE PLUGGED BUT NOT TO USGS REQUIREMENTS, HENCE LATER WORK WAS REQUIRED.
HILDA CONF. 1964	CONTAINED QUARTERS BUILDING AND 5 STORAGE TANKS TOTALING 17,000 BBLS. 4 COMPLETED OIL WELLS. 3500 BBLS ON BOARD AT TIME OF COLLAPSE.





Production platform in Eugene Island area with five wells and storage facilities was completely destroyed. Photo at top shows installation before Hilda. After storm (bottom), only small treater platform remains intact. Disturbed water adjacent to treater platform is due to broken flow line or leakage from well bore.

Lambert, D. E., "Operators Look at Hilda's Damage," World Oil, November 1964, pp. 11-25.

EUGENE ISLAND 175-A

HILDA

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 10:33:23

PLATFORM NAME : EUGENE ISLAND 188
COMPANY NAME : SHELL

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: WELL PROTECTOR
Water Depth (ft)	: 70
Number of Piles	: 4
Number of Wells	:
Install\Design Date	: 07/01/58
Design Criteria	: 100 YEAR
Deck Elevation (ft)	: 20
Original Plat. Cost	:
Comments	: "CLOSED-SIDE" WELL PROTECTOR

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
HILDA CONF. 1964	PLATFORM WAS SALVAGED AND INVESTIGATED. BRACES APPEARED TO BE PULLED OUT OF LEGS IN A "COUPON" FAILURE MODE. INVESTIGATORS BELIEVE THIS INDICATED JOINT FAILURE.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:51:05

PLATFORM NAME : EUGENE ISLAND 198
COMPANY NAME : PLACID

STORM : CARLA DATE : 09/01/61

DAMAGE SUMMARY : SEVERE DAMAGE

PLATFORM INFORMATION

Platform Type :	
Water Depth (ft) :	102
Number of Piles :	2
Number of Wells :	
Install\Design Date :	
Design Criteria :	
Deck Elevation (ft) :	
Original Plat. Cost :	
Comments :	

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1981	CONNECTION FROM BRACE-CAISSON FAILURE.
LEE, G. 1988	PLATFORM WAS SALVAGED AND REPLACED -- NEW JACKET WITH OLD DECK, RAISED TO +50 FEET. JACKET WAS REBUILT AND USED AT NEW LOCATION AT A LATER DATE.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:51:29

PLATFORM NAME : EUGENE ISLAND 198-B
COMPANY NAME : PLACID

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: SINGLE WELL
Water Depth (ft)	: 102
Number of Piles	: 2
Number of Wells	: 1
Install\Design Date	: 01/07/61
Design Criteria	: 25 YEAR
Deck Elevation (ft)	: 40
Original Plat. Cost	:
Comments	: TWO PILE CAISSON BRACE.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1988	PLATFORM WAS SALVAGED AND REPLACED -- NEW JACKET WITH OLD DECK, RAISED TO +50 FEET. JACKET WAS REBUILT AND USED AT NEW LOCATION AT A LATER DATE.

---------------- AIM Failure Consequences Database -------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:51:43

PLATFORM NAME : EUGENE ISLAND 208-A
COMPANY NAME : CATC

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: TENDER TYPE
Water Depth (ft)	: 100
Number of Piles	: 8
Number of Wells	: 4
Install\Design Date	:
Design Criteria	: 25 YEAR
Deck Elevation (ft)	:
Original Plat. Cost	:
Comments	:

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
HILDA CONF. 1964	JACKET WAS PREVIOUSLY DAMAGED BY COLLISION AND HAD NOT YET BEEN REPAIRED AT THE TIME OF THE STORM. THIS PLATFORM WAS NOT AT ITS ORIGINAL DESIGN STRENGTH.
OGJ, 10/19/64	CONTINENTAL SAYS ITS LOSSES FOR THE ENTIRE STORM WILL COME IN "UNDER $2 MILLION," MOST OF WHICH WILL BE COVERED BY INSURANCE RESERVE.
MMS, 1986	BLOWOUT, 5180 BBLS SPILLED, BETWEEN PLATFORMS 208-A,C,&D, GAS AND OIL, SPREAD OVER SEVERAL DAYS. WELLS EVENTUALLY CEMENTED. NO RECORDED ENVIRONMENTAL DAMAGE.
OGJ, 11/9/64	PLATFORM SALVAGED FOR JUNK BY BROWN AND ROOT. CATC EXPECTS TO REDRILL SOME OR ALL WELLS.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 10:34:36

PLATFORM NAME : EUGENE ISLAND 208-C
COMPANY NAME : CATC

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: TENDER TYPE
Water Depth (ft)	: 96
Number of Piles	: 8
Number of Wells	: 4
Install\Design Date	: 07/01/59
Design Criteria	: 25 YEAR
Deck Elevation (ft)	: 42
Original Plat. Cost	:
Comments	:

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
MMS, 1986	BLOWOUT, 5100 BBLS SPILLED, BETWEEN PLATFORMS A, C & D, GAS AND OIL, OVER SEVERAL DAYS. WELLS EVENTUALLY CEMENTED. NO RECORDED ENVIRONMENTAL DAMAGE.
CONOCO, 1988	PLATFORM LOSS COST EQUALS $726,000. $800,000 COST TO REMOVE ALL CATC DEBRIS CAUSED BY HILDA.
OGJ, 10/19/64	CONTINENTAL SAYS ITS NET LOSSES FOR THE ENTIRE STORM WILL COME IN "UNDER $2 MILLION," MOST OF WHICH WILL BE COVERED BY INSURANCE RESERVE.
OGJ, 11/9/64	PLATFORM SALVAGED FOR JUNK BY BROWN AND ROOT. CATC EXPECTS TO REDRILL ALL OR SOME WELLS.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:52:29

PLATFORM NAME : EUGENE ISLAND 208-D
COMPANY NAME : CATC

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type : TENDER
Water Depth (ft) : 97
Number of Piles : 8
Number of Wells : 5
Install\Design Date :
Design Criteria : 25-YEAR
Deck Elevation (ft) : 42
Original Plat. Cost :
Comments : QUARTERS BUILDING AND PRODUCTION EQUIP WEIGHT = 100 TONS

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
OGJ, 11/9/64	SALVAGED FOR JUNK BY BROWN & ROOT. ONE WELL BUBBLED GAS. CATC EXPECTS TO REDRILL ALL OR SOME WELLS.
CONOCO, 1988	PLATFORM LOSS COST EQUALS $630,000.
OGJ, 10/19/64	CONTINENTAL SAYS ITS NET LOSSES FOR THE ENTIRE STORM WILL COME IN "UNDER $2 MILLION," MOST OF WHICH WILL BE COVER BY INSURANCE RESERVE.
LEE, G. 1988	JACKET FAILED ABOVE SECOND HORRIZONTAL ELEVATION (AT -72') INTACT BELOW.
MMS, 1986	BLOWOUT, 5100 BBLS SPILLED, BETWEEN PLATFORMS 208-A, C, & D, GAS AND OIL, OVER SEVERAL DAYS. WELLS EVENTUALLY CEMENTED. NO RECORDED ENVIRONMENTAL DAMAGE.

---------------- AIM Failure Consequences Database --------------------
----------------   Individual Case Report   --------------------

Date : 09/11/88
Time : 8:52:43

PLATFORM NAME : EUGENE ISLAND 276
COMPANY NAME : UNION

STORM : HILDA   DATE : 10/03/64

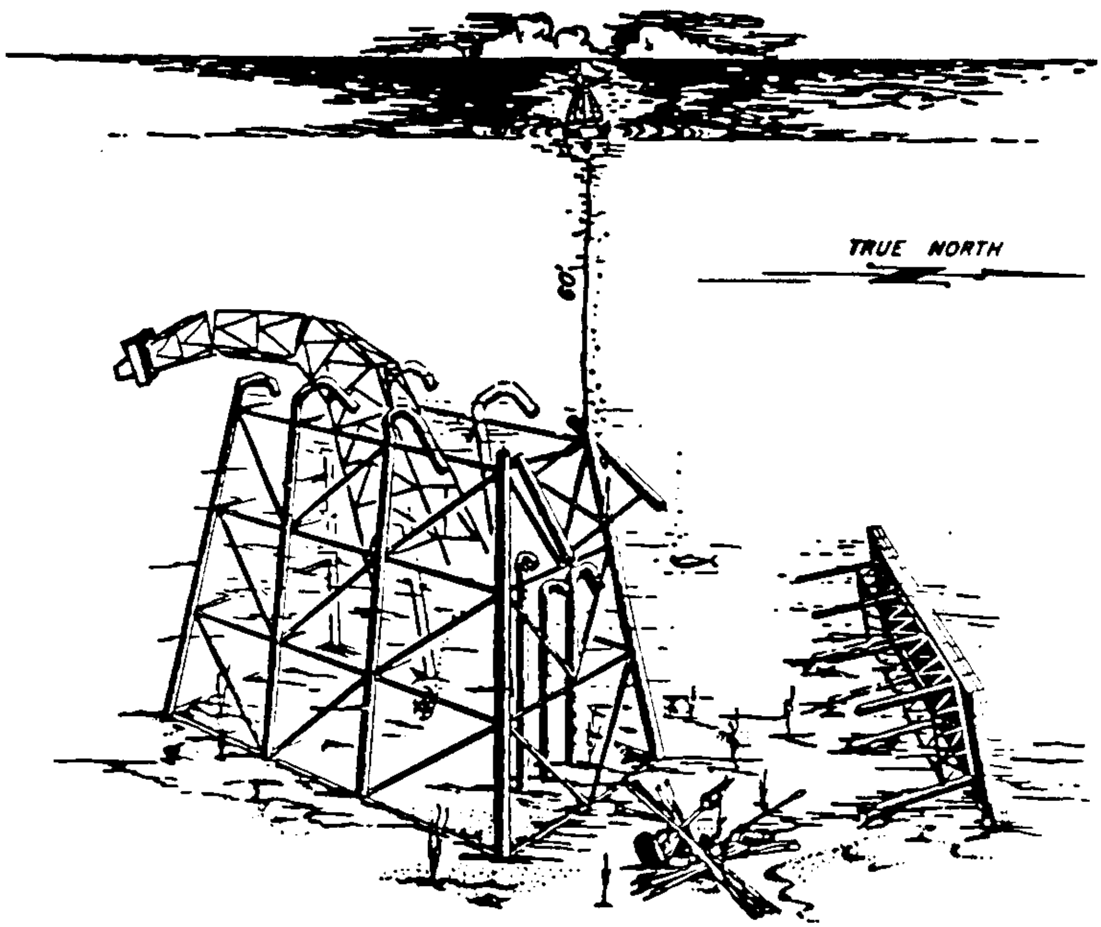
DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: SELF-CONTAINED
Water Depth (ft)	: 172
Number of Piles	: 8
Number of Wells	: 12
Install\Design Date	: 07/01/64
Design Criteria	: 25-YEAR
Deck Elevation (ft)	: 31
Original Plat. Cost	: $1 MILLION
Comments	: ONLY 3 WELLS WERE INSTALLED AT THE TIME OF HILDA.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
WORLD OIL, 1964	UNION REPORTS IT WILL COST $2 MILLION TO REDRILL WELLS IF THAT IS THE DECISION.
HILDA CONF. 1964	JACKET WAS PRETTY MUCH INTACT FROM -60' DOWN TO THE SEAFLOOR. ONLY ONE OF THE THREE WELLS DRILLED SO FAR HAD BEEN COMPLETED AND IT WAS NOT LEAKING.
OGJ, 10/12/64	BREWSTER-BARTLE RIG LOST WITH PLATFORM WAS WORTH MORE THAN $1 MILLION. DRILLER WAS ON THIRD WELL WHEN STORM STRUCK.
OGJ, 11/9/64	UNION PLANS TO ABANDON THE 3 WELLS DRILLED FROM THE SUNKEN PLATFORM AND ERECT ANOTHER PLATFORM AT A NEW SITE IN THE SAME BLOCK.



EUGENE ISLAND 276
HILDA

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:52:59

PLATFORM NAME : GRANDE ISLAND 1
COMPANY NAME : HUMBLE

STORM : GRND ISL DATE : 09/01/48

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type : TENDER
Water Depth (ft) : 50
Number of Piles :
Number of Wells :
Install\Design Date :
Design Criteria : NONE
Deck Elevation (ft) :
Original Plat. Cost :
Comments : TEMPORARY PLATFORM WITH UNBRACED PILES

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE. G, 1981	COLLAPSE

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:53:10

PLATFORM NAME : GRANDE ISLAND 2
COMPANY NAME : HUMBLE

STORM : GRND ISL DATE : 09/01/48

DAMAGE SUMMARY : SEVERE DAMAGE

PLATFORM INFORMATION

Platform Type : TENDER
Water Depth (ft) : 50
Number of Piles :
Number of Wells :
Install\Design Date :
Design Criteria : NONE
Deck Elevation (ft) :
Original Plat. Cost :
Comments : TEMPORARY PLATFORM WITH UNBRACED PILES

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1981	"S" CURVE IN PILES

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:53:24

PLATFORM NAME : MAIN PASS 129
COMPANY NAME : PHILLIPS

STORM : BETSY DATE : 09/09/65

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: WELL PROTECTOR
Water Depth (ft)	: 92
Number of Piles	: 4
Number of Wells	:
Install\Design Date	:
Design Criteria	: 25-YEAR
Deck Elevation (ft)	: 36
Original Plat. Cost	:
Comments	:

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1981	LOST.

---------------- AIM Failure Consequences Database -------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 10:35:31

PLATFORM NAME : S. TIMBALIER 86 PL.A
COMPANY NAME : ODECO

STORM : JUAN DATE : 09/27/85

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type :
Water Depth (ft) : 95
Number of Piles : 16
Number of Wells :
Install\Design Date : 01/01/55
Design Criteria : 25 YEAR
Deck Elevation (ft) :
Original Plat. Cost :
Comments : LATE SEASON HURRICANE DEVELOPED QUICKLY WITH MANY RIGS UNABLE TO EVACUATE.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
MMS, 1987	JULY 1985 UNDERWATER SURVEY DETECTED SERIOUS CORROSION DAMAGE CONSISTING OF HOLES (SOME UP TO 32x48 ") IN BRACES. MECHANICAL CLAMPS USED FOR REPAIR. CREW DECTECTED BROKEN & MISSING MEMBERS VISIBLE BENEATH WATER FROM DECK.
MMS, 1987	CREW UNABLE TO EVACUATE DUE TO FAST MOVING STORM BUT WERE ABLE TO SHUT-IN WELLS. SEVERAL WELL CASINGS BROKE LOOSE IN THE STORM. CREW PROCEEDED TO ATTEMPT TO SECURE CASINGS FROM CELLAR DECK. AT THAT TIME, ONE LARGE WAVE KNOCKED ONE CREW INTO WATER.
MMS, 1987	THE MMS REPORT RECOMMENDED THE MMS REQUIRE ALL OPERATORS TO SUBMIT AN INSPECTION REPORT AND A PLAN OF EVACUTION FOR ALL MANNED PLATFORMS. FOR UNMANNED PLATFORMS, A REPORT ON THE CONDITION OF THE PLATFORM SHOULD BE SUBMITTED.
OGJ, 11/4/85	CITING THIS INCIDENT AS BACKGROUND, BILL TAUZIN (D-La.) FURTHER PRESSED HIS ISSUE TO REQUIRE STANDBY VESSELS FOR MANNED PLATFORMS. STATUS OF TAUZIN'S BILL IN CONGRESS IS UNKNOWN.
MMS, 1987	PLATFORM FAILED COMPLETELY ON NEXT LARGE WAVE. 5 CREW PICKED UP NEXT DAY AFTER SPENDING UP TO 21 HOURS IN THE WATER. ONE CREW MEMBER SUSTAINED HIP INJURY. THE INCIDENT DID NOT INDUCE ANY POLLUTION.
MMS, 1987	MMS CONDUCTED AN EXTENSIVE INVESTIGATION INTO THE FAILURE REPORTED IN OCS REPORT MMS 87-0075.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:56:05

PLATFORM NAME : SHIP SHOAL 119-A
COMPANY NAME : ODECO

STORM : CARMEN DATE : 08/07/74

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type : CENTRAL FACILITY
Water Depth (ft) : 51
Number of Piles : 36
Number of Wells :
Install\Design Date :
Design Criteria :
Deck Elevation (ft) :
Original Plat. Cost :
Comments : CENTRAL PRODUCTION FACILITY WITH NO WELLS. AN OLD REUSED PLATFORM.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1981	PLATFORM TOPPLED AS THE RESULT OF COLLISION BY BARGE DURING STORM.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 9:03:22

PLATFORM NAME : SHIP SHOAL 119-F
COMPANY NAME : ODECO

STORM : CARMEN DATE : 08/07/74

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type : CENTRAL FACILITY
Water Depth (ft) : 51
Number of Piles : 36
Number of Wells : 0
Install\Design Date :
Design Criteria :
Deck Elevation (ft) :
Original Plat. Cost :
Comments : CENTRAL PRODUCTION FACILITY WITH NO WELLS.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
OFFSHORE, 10/74	CONTROL STATION WITH 5 WELLS TIED INTO PLATFORM. ALL WELLS SHUT-IN PRIOR TO STORM. NO LEAKS FROM FLOWLINES.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:56:31

PLATFORM NAME : SHIP SHOAL 149-B
COMPANY NAME : SIGNAL

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: TENDER TYPE
Water Depth (ft)	: 50
Number of Piles	: 8
Number of Wells	:
Install\Design Date	:
Design Criteria	: 25 YEAR
Deck Elevation (ft)	: 38
Original Plat. Cost	: $450,000
Comments	: OIL STORAGE PLATFORM SUPPORTING A 10,000 BBL RECTANGULAR TANK.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
HILDA CONF. 1964	THE TANK WHICH CONTAINED SOME OIL IS MISSING.
PIPELINE IND., 11/64	6 WELLS WERE SHUT-IN ON NEARBY PLATFORMS DUE TO THE LOSS OF THIS STORAGE PLATFORM.
MMS, MAY 1986	5100 BBLS LOST FROM TANK.
OGJ, 11/9/64	LOSS OF THIS STORAGE FACILITY CAUSED SIGNAL TO SHUT-IN ABOUT 650 BBL/DAY FROM ELSEWHERE.

---------------- AIM Failure Consequences Database -------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:56:44

PLATFORM NAME : SHIP SHOAL 154-B
COMPANY NAME : GULF

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type : TENDER TYPE
Water Depth (ft) : 60
Number of Piles : 6
Number of Wells :
Install\Design Date :
Design Criteria : 25 YEAR
Deck Elevation (ft) : 39
Original Plat. Cost :
Comments :

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
PIPELINE IND., 11/64	GULF ESTIMATES $4 MILLION TOTAL PROPERTY DAMAGE FOR STORM.
HILDA CONF. 1964	3 OIL WELLS. ONE OF GULF'S FIRST TENDER PLATFORMS.
LEE, G. 1988	JACKET FELL OVER. LOWER BRACING TELESCOPED ON HITTING BOTTOM.
CHEVRON, 1988	NO OIL SPILLED. PLATFORM SALVAGED.
MMS, 1986	GAS BLOWOUT. 15 DAYS. CONTROLLED BY BRIDGING.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:56:54

PLATFORM NAME : SHIP SHOAL 154-H
COMPANY NAME : GULF

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: TENDER TYPE
Water Depth (ft)	: 60
Number of Piles	: 6
Number of Wells	: 3
Install\Design Date	:
Design Criteria	: 25-YEAR
Deck Elevation (ft)	: 39
Original Plat. Cost	:
Comments	: VERTICAL LEG TENDER PLATFORM.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
CHEVRON, 1988	APPARENTLY NO BLOWOUTS OR SPILLS.
PIPELINE IND., 11/64	GULF ESTIMATES $4 MILLION TOTAL PROPERTY DAMAGE FROM STORM.
HILDA CONF. 1964	3 OIL WELLS. ALSO ONE OF GULF'S FIRST TENDER PLATFORMS.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 10:25:44

PLATFORM NAME : SHIP SHOAL 169-A
COMPANY NAME : GULF

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : SEVERE DAMAGE

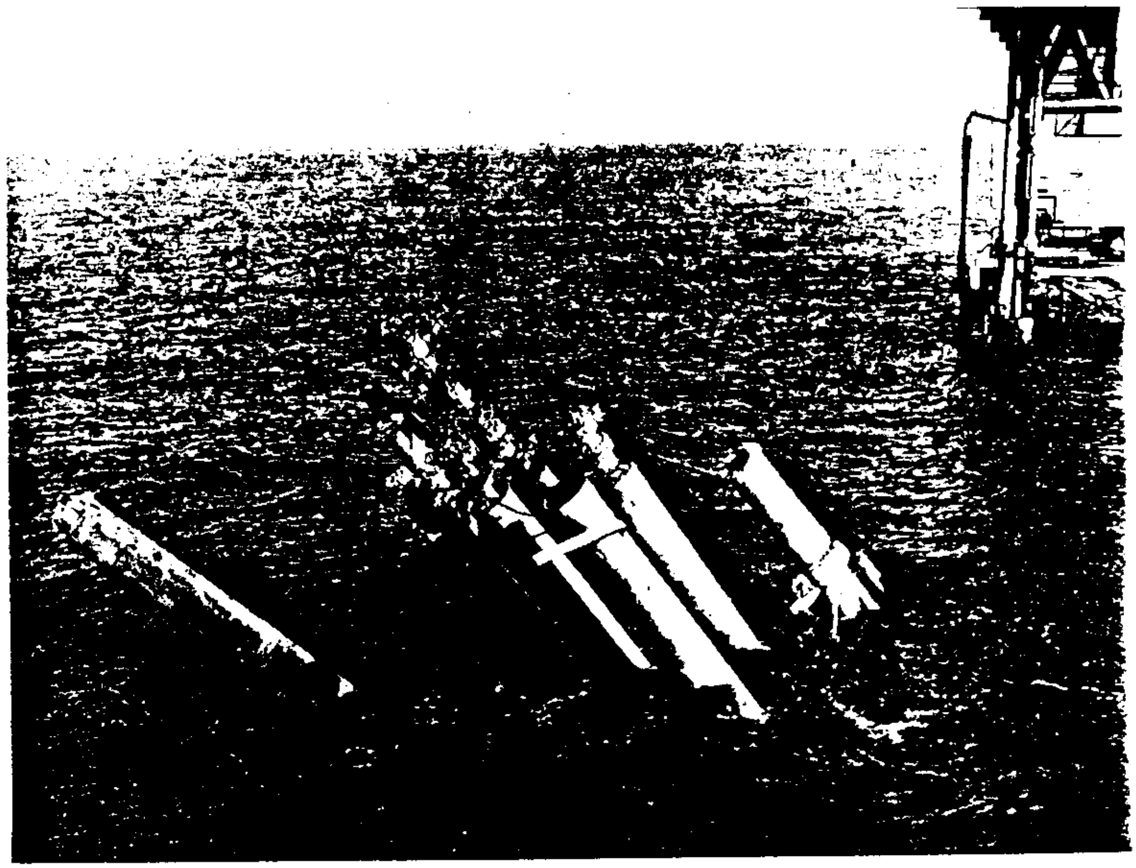
PLATFORM INFORMATION

Platform Type : WELL PROTECTOR
Water Depth (ft) : 60
Number of Piles : 4
Number of Wells : 5
Install\Design Date : 01/07/61
Design Criteria : 25 YEAR
Deck Elevation (ft) : 39
Original Plat. Cost :
Comments : FOUR GAS WELLS AND ONE OIL WELL CONNECTED TO A 4-PILE WELL PROTECTOR.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
HILDA CONF. 1964	APPARENTLY AN OLD WELL JACKET WITH 5 WELLS IS LISTING 45 DEGREES; DECK LOST.
PIPELINE IND., 11/64	GULF ESTIMATES $4 MILLION TOTAL PROPERTY DAMAGE FOR THE STORM.

SHEARED PLATFORM is in Block 169, Ship Shoal Area. Only the piles of Gulf Oil Corp.'s five-well platform remain above the surface.



"Hurricane Hilda's Trail is Still Well Marked," The Oil & Gas Journal, October 19, 1964, pp. 48-49.

SHIP SHOAL 169

HILDA

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:57:03

PLATFORM NAME : SHIP SHOAL 198-C
COMPANY NAME : TENNECO

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type : TENDER TYPE
Water Depth (ft) : 96
Number of Piles : 8
Number of Wells : 3
Install\Design Date : 07/01/59
Design Criteria : 25 YEAR
Deck Elevation (ft) : 36
Original Plat. Cost :
Comments : 2 OIL AND 1 GAS WELLS.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
OGJ, 11/9/64	COLLAPSE.

AIM Failure Consequences Database

Individual Case Report

Date : 09/11/88
Time : 8:57:18

PLATFORM NAME : SHIP SHOAL 199-A
COMPANY NAME : TENNECO

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	TENDER TYPE
Water Depth (ft)	101
Number of Piles	8
Number of Wells	6
Install\Design Date	07/01/59
Design Criteria	25 YEAR
Deck Elevation (ft)	36
Original Plat. Cost	
Comments	3 OIL AND 3 GAS WELLS.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
OGJ, 11/9/64	QUESTIONABLE IF PLATFORM CAN BE SALVAGED.
HILDA CONF. 1964	THERE WAS A CONSIDERABLE AMOUNT OF EQUIPMENT ON THE CELLAR DECK.
HILDA CONF. 1964	PLATFORM COLLAPSED VERTICALLY. ONE WELL LEAKING; HOWEVER, THIS WELL HAD BEEN 100% SALT WATER BEFORE HILDA.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:57:29

PLATFORM NAME : SHIP SHOAL 253
COMPANY NAME : PURE

STORM : HILDA DATE : 10/03/64

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type : SELF CONTAINED
Water Depth (ft) : 172
Number of Piles : 8
Number of Wells : 12
Install\Design Date : 07/01/64
Design Criteria : 25-YEAR
Deck Elevation (ft) : 34
Original Plat. Cost : 1.2 MILL
Comments : NO GROUTING OR JOINT CANS.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1988	JACKET FAILED -60'TO -80'. DECK ON TO OF RIG ON WEST SIDE.
HILDA CONF., 1964	THE CELLAR DECK WAS "CLUTTERED" WITH EQUIPMENT. SISTER PLATFROM NEARBY HAD A "CLEAN" DECK & STAYED UP IN STORM.
OGJ, 10/12/64	A NEW FALCON SEABOARD RIG LOST WITH PLATFORM WAS WORTH $1.7 MILLION. RIG WAS DRILLING FIRST WELL WHEN SHUT DOWN FOR STORM.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:57:44

PLATFORM NAME : SOUTH PASS 24
COMPANY NAME : SHELL

STORM : BETSY DATE : 09/09/65

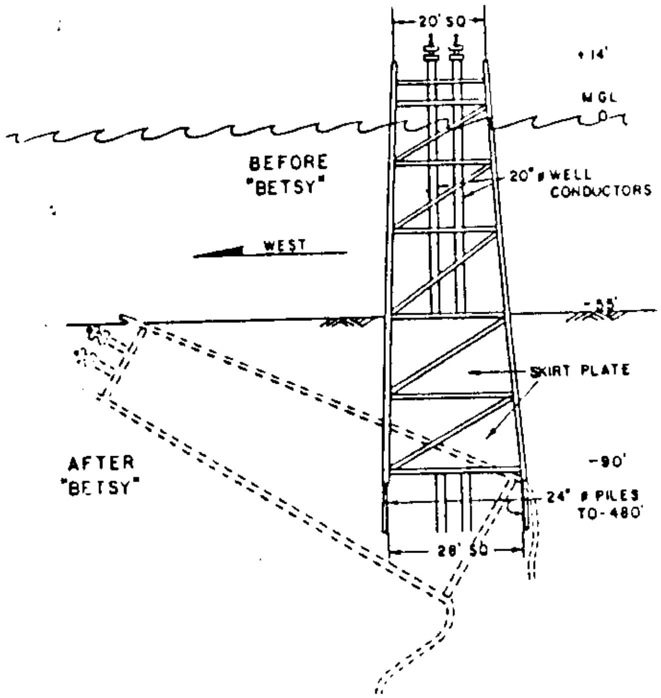
DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: WELL PROTECTOR
Water Depth (ft)	: 60
Number of Piles	: 4
Number of Wells	: 2
Install\Design Date	:
Design Criteria	: 100-YEAR
Deck Elevation (ft)	:
Original Plat. Cost	:
Comments	: STRUCTURE HAS A LARGE PLATED SECTION (SKIRT PLATES) BELOW THE MUDLINE.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
BEA & AUDIBERT, 1980	MUDSLIDE FAILURE. STRUCTURE WAS FOUND TOPPLED OVER AND PUSHED BELOW THE MUDLINE. ONLY THE TOPS OF TWO LEGS AND THE TWO WELL HEADS COULD BE LOCATED.
BEA & AUDIBERT, 1980	DURING THE WINTER STORMS THAT FOLLOWED BETSY, CONTINUED MOVEMENT OF THE BOTTOM COVERED AND PUSHED THE STRUCTURE DOWN SO THAT IT COULD NOT BE LOCATED AGAIN.
BEA & AUDIBERT, 1980	FOLLOWING LOCATION OF THE STRUCTURE, THE WELLS WERE PLUGGED WITH CEMENT. NO LOSS OF HYDROCARBONS DUE TO DOWN-HOLE SAFETY EQUIPMENT.
LEE, G. 1988	JACKET FAILED UNDERWATER



Bea, R. G. and Audibert, M. E., "Offshore Platforms and Pipelines in Mississippi River Delta," Journal of the Geotechnical Engineering Division, ASCE, August 1980, pp. 853-869.

SOUTH PASS 24

BETSY

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 17:58:24

PLATFORM NAME : SOUTH PASS 61-A
COMPANY NAME : GULF

STORM : CAMILLE DATE : 10/07/69

DAMAGE SUMMARY : COLLAPSE

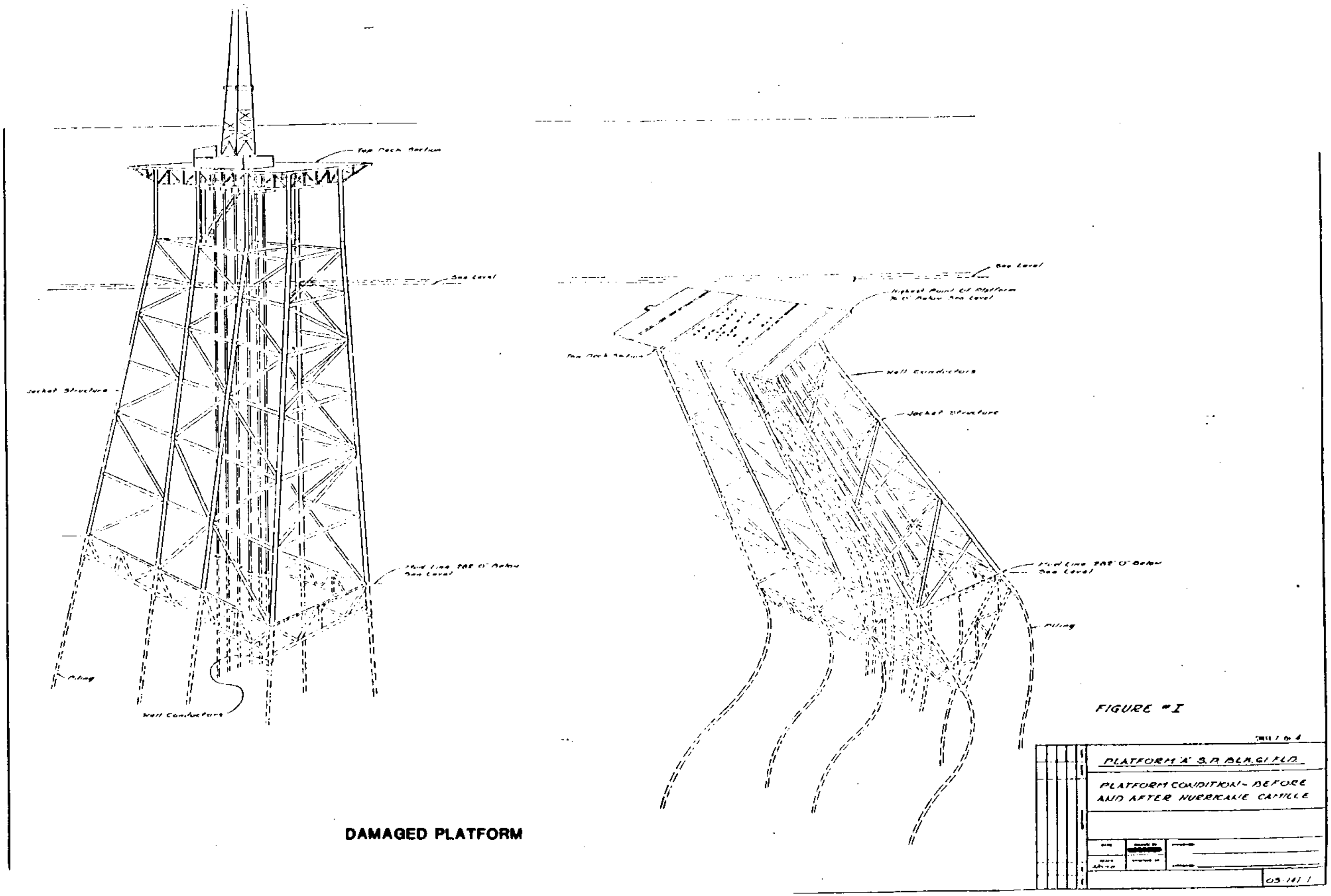
PLATFORM INFORMATION

Platform Type	: SELF CONT.
Water Depth (ft)	: 280
Number of Piles	: 8
Number of Wells	: 16
Install\Design Date	: 06/01/68
Design Criteria	: 100 YEAR
Deck Elevation (ft)	:
Original Plat. Cost	: $3.8 MILLION
Comments	: 13 OIL COMPLETIONS, 1 GAS COMPLETION, AND 2 UNPERFORATED WELL BORES.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
OFFSHORE, 09/69	HIGH SEAS RIG LOSS IS ESTIMATED AT $1 MILLION.
CHEVRON, 1988	COSTS & DURATIONS (ESTIMATED) 1970: FOR P&A OF 16 WELLS (14 COMPLETIONS)--$1.5 MIL, 50 DAYS; FOR PLATFORM SALVAGE & DISPOSAL --$2.5 MIL, 75 DAYS; FOR A TOTAL OF $3.5 MIL, 125 DAYS.
CHEVRON, 1988	CONSIDERATION WAS GIVEN TO SELLING THE PLATFORM FOR REUSE OR RELOCATING TO W.D. 117'.
OGS 08/25/69	"HIGH SEAS" NEW WORKOVER RIG SANK WITH PLATFORM. PLATFORM HAD BEEN INSTALLED PREVIOUS YEAR. RIG WAS POSSIBLY SALVAGED.
GULF, 05/12/70	NO STRUCTURAL FAILURES WERE LOCATED IN THE JACKET OR DECK SECTION.
CHEVRON, 1988	APPARENTLY, WELLS WERE P&A'D, AND PLATFORM WAS REMOVED & DISPOSED NEAR CENTER OF EXPLOSIVE DUMPING AREA IN GULF OF MEXICO. ARMY CORP REQ'D ALL STRUCTURE PARTS BE REMOVED TO 6' BELOW M.L.; USGS REQ'D TO 15' BELOW M.L. IT IS UNCLEAR WHICH WAS PERFORMED.
CHEVRON, 1988	AVERAGE BID: (1) $2.5 MILLION TO CUT TO 15' BELOW M.L. AND DISPOSE OF PLATFORM; (2) $2.3 MILLION TO CUT TO M.L. AND DISPOSE OF PLATFORM.
OGS 08/25/69	GULF REPORTEDLY HAD A $5 MILLION DEDUCTIBLE INSURANCE POLICY COVERING ITS MARINE FACILITIES IN THE AREA. RIG WAS ALSO COVERED BY INSURANCE.

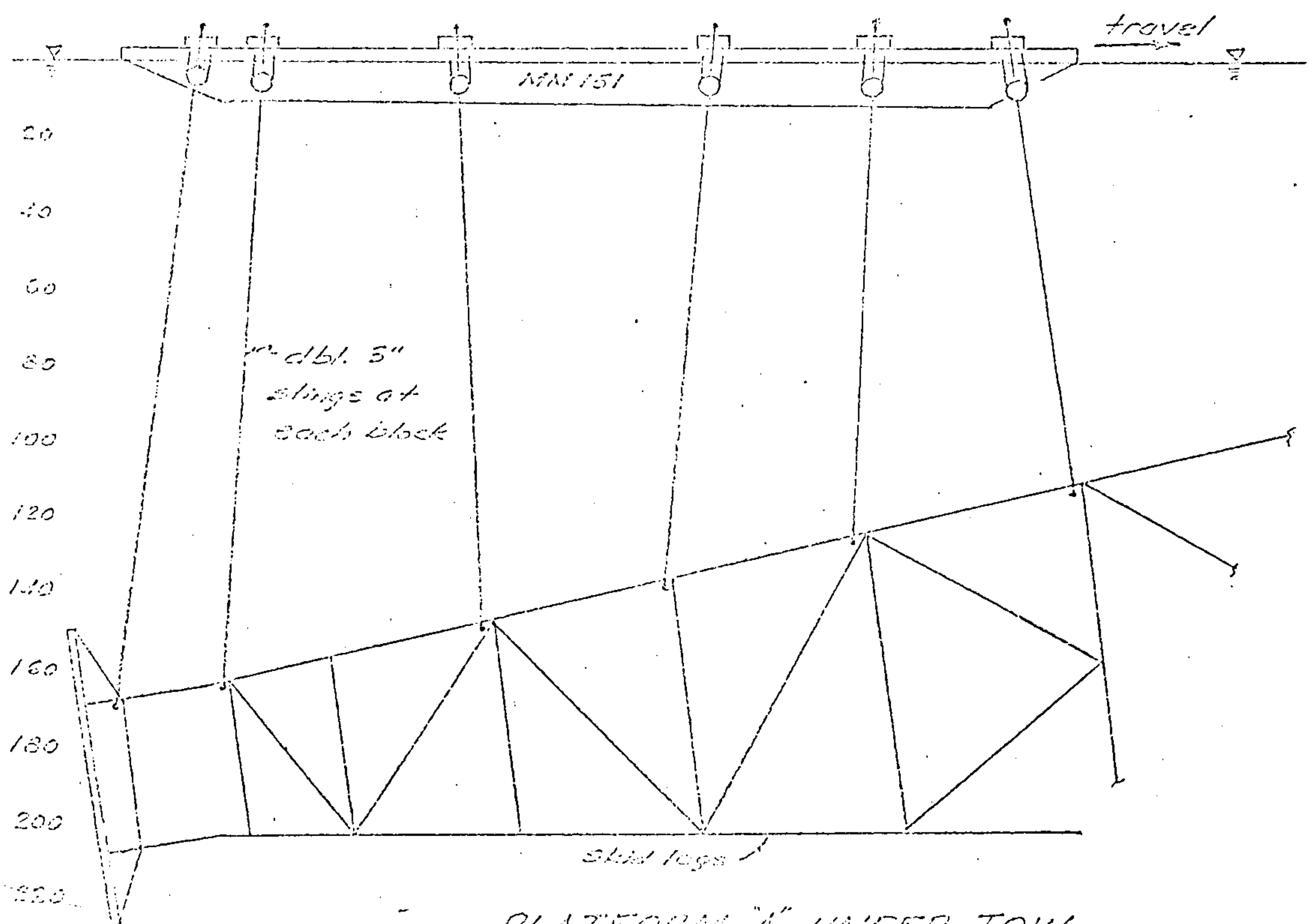
CHEVRON, 1988	PLATFORM TWISTED AND PUSHED TO A 55 DEGREE LIST AND DOWN TO 10 FEET UNDERWATER DUE TO MUDSLIDE. SMALL GAS LEAK, NO OIL SPILLED.



DAMAGED PLATFORM

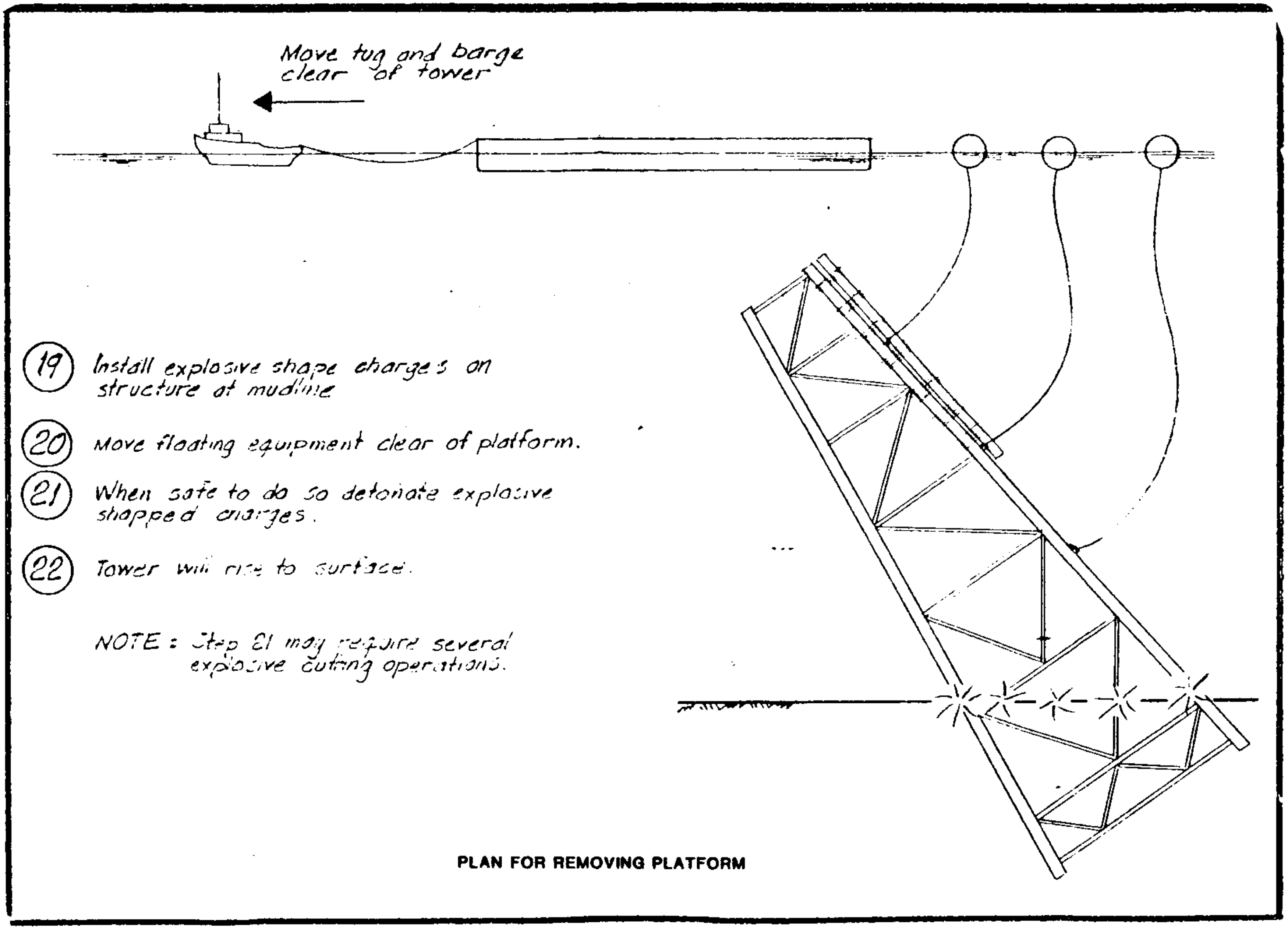
SOUTH PASS 61-A CAMILLE

Lift by 12 ea. 500T blocks



PLATFORM "A" UNDER TOW

SOUTH PASS 61-A   CAMILLE   **TOWING PLATFORM FOR DISPOSAL**



PLAN FOR REMOVING PLATFORM

SOUTH PASS 61-A CAMILLE

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:58:09

PLATFORM NAME : SOUTH PASS 70-A
COMPANY NAME : SHELL

STORM : CAMILLE DATE : 08/17/69

DAMAGE SUMMARY : SEVERE DAMAGE

PLATFORM INFORMATION

Platform Type : SELF-CONTAINED
Water Depth (ft) : 310
Number of Piles : 16
Number of Wells : 24
Install\Design Date : 07/01/69
Design Criteria : 100-YEAR
Deck Elevation (ft) :
Original Plat. Cost : $6 MILLION.
Comments : 8 MAIN PILES AND 8 SKIRT PILES. FEW WELLS COMPLETED AT TIME OF STORM.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1981	MUDSLIDE. "S" CURVE IN PILES BELOW MUDLINE.
BEA, ET. AL., 10/80	PLATFORM WAS PUSHED DOWNSLOPE SOME 4 TO 5 FEET AT ITS BASE. IT REMAINED STANDING. DRILLING OPERATIONS RESUMED; DRILLING DIFFICULTIES AROSE DUE TO THE DAMAGE (DISPLACED BOTTOM) AND THE PLATFORM WAS EVENTUALLY SALVAGED.
BEA & AUDIBERT, 1980	PLATFORM APPEARED INTACT IMMEDIATELY FOLLOWING CAMILLE. HOWEVER, PRECISION SURFACE SURVEYING AND SURVEYING OF THE WELL OCNDUCTOR DEFORMATIONS INDICATED THE STRUCTURE DISPLACED 4-5 FEET DOWNSLOPE.

---------------- AIM Failure Consequences Database -------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 10:37:10

PLATFORM NAME : SOUTH PASS 70-B
COMPANY NAME : SHELL

STORM : CAMILLE DATE : 08/17/69

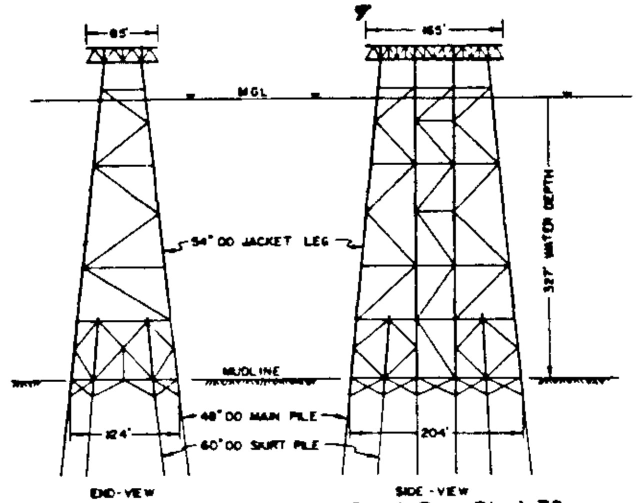
DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

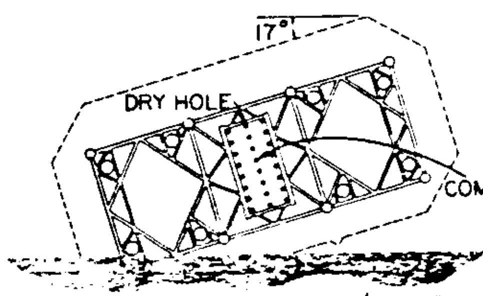
Platform Type	: SELF-CONTAINED
Water Depth (ft)	: 327
Number of Piles	: 16
Number of Wells	: 24
Install\Design Date	: 07/01/69
Design Criteria	: 100 YR
Deck Elevation (ft)	:
Original Plat. Cost	: $6 MILL
Comments	: 8 MAIN AND 8 SKIRT PILES. 1 COMPLETED WELL AND 1 DRY HOLE AT TIME OF CAMILLE.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

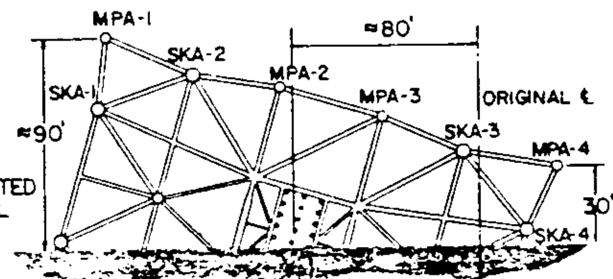
SOURCE	DETAIL
STERLING, 3/80	PLATFORM FELL IN ONE PIECE TO SEAFLOOR WITH ALL BRACES INTACT. THE STRUCTURE WAS PARTIALLY BURIED IN THE MUD.
OGJ, 8/25/69	COLLAPSE DUE TO MUDSLIDE. SISTER PLATFORM AT 70-B REMAINED STANDING, BUT SEVERELY DAMAGED.
BEA, 1988	PLATFORM WAS EVENTUALLY CUT UP AND SALVAGED.
BEA, ET. AL., 10/80	PLATFORM FELL TO WEST AND MOVED DOWNSLOPE ABOUT 100 FT. PILES FILED IN BENDING. THERE WAS NO EVIDENCE OF PILE PULLOUT.



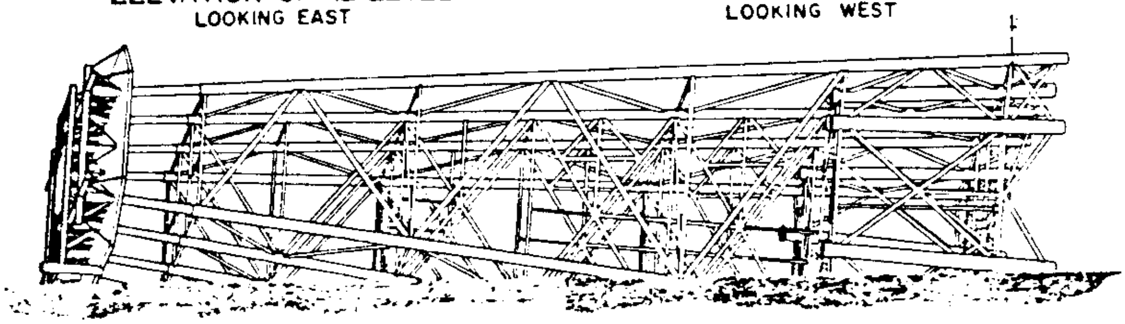
Side and end view, South Pass Block 70
Platform B



ELEVATION OF +12' LEVEL
LOOKING EAST



ELEVATION OF -327' LEVEL
LOOKING WEST



ELEVATION
LOOKING NORTH

South Pass Block 70 Platform B on the bottom.

SOUTH PASS 70-B

CAMILLE

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:58:42

PLATFORM NAME : SOUTH PELTO 19 #11
COMPANY NAME : ODECO

STORM : FREDERIC DATE : 08/01/79

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type : SINGLE WELL JACKET
Water Depth (ft) : 30
Number of Piles : 3
Number of Wells :
Install\Design Date :
Design Criteria :
Deck Elevation (ft) :
Original Plat. Cost :
Comments :

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1981	TOPPLED DURING STORM.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:58:53

PLATFORM NAME : SOUTH PELTO 19 #13
COMPANY NAME : ODECO

STORM : FREDERIC DATE : 08/01/79

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: SINGLE WELL JACKET
Water Depth (ft)	: 30
Number of Piles	: 3
Number of Wells	:
Install\Design Date	:
Design Criteria	:
Deck Elevation (ft)	:
Original Plat. Cost	:
Comments	:

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1981	TOPPLED DURING STORM.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:59:07

PLATFORM NAME : SOUTH PELTO 19 #4
COMPANY NAME : ODECO

STORM : FREDERIC DATE : 08/01/79

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: SINGLE WELL JACKET
Water Depth (ft)	: 30
Number of Piles	: 3
Number of Wells	:
Install\Design Date	:
Design Criteria	:
Deck Elevation (ft)	:
Original Plat. Cost	:
Comments	:

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1981	TOPPLED DURING STORM.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:59:15

PLATFORM NAME : SOUTH PELTO 19 OBM
COMPANY NAME : ODECO

STORM : JUAN DATE : 10/27/85

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type : OBM HEADER PLATFROM
Water Depth (ft) : 30
Number of Piles : 4
Number of Wells :
Install\Design Date : 01/01/61
Design Criteria :
Deck Elevation (ft) :
Original Plat. Cost :
Comments : UNMANNED FOUR PILE JACKET.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
MMS, 1987	PLATFORM REMOVED AND BROUGHT TO SHORE. INSPECTION REVEALED STRUCTURE WAS SEVERELY DETERIORATED. NO CATHODIC PROTECTION REMAINED. MARINE GROWTH INSIDE LEGS INDICATING LARGE CRACKS FOR SOME TIME. FURTHER DETAILS IN THE MMS REPORT.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:59:26

PLATFORM NAME : SOUTH PELTO 19 SWP
COMPANY NAME : ODECO

STORM : JUAN DATE : 10/27/85

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type : SINGLE WELL PROTECTR
Water Depth (ft) :
Number of Piles : 3
Number of Wells :
Install\Design Date :
Design Criteria :
Deck Elevation (ft) :
Original Plat. Cost :
Comments :

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
MMS, 1987	STRUCTURE APPEARED IN GOOD CONDITION. NO EVIDENCE OF PREVIOUS REPAIRS. STRUCTURE FAILED AS A UNIT, PROBABLY DUE TO PILE FAILURE AT THE MUDLINE AS A RESULT OF GROSS OVERLOAD. FURTHER DETAILS IN THE MMS REPORT.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:59:37

PLATFORM NAME : VERMILLION 104
COMPANY NAME : ZAPATA

STORM : CARLA DATE : 09/01/61

DAMAGE SUMMARY : SEVERE DAMAGE

PLATFORM INFORMATION

Platform Type	: WELL PROTECTOR
Water Depth (ft)	: 60
Number of Piles	: 4
Number of Wells	:
Install\Design Date	: 01/08/60
Design Criteria	:
Deck Elevation (ft)	:
Original Plat. Cost	:
Comments	: 4 PILE PROTECTIVE STYRUCTURE

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
McCLND. & COX, 1976	PILES PULLED OUT 8 INCHES DURING STORM. JETTING DURING INSTALLATION TO OPEN PILOT HOLES BENEATH PILE MAY HAVE WEAKENED SOILS, LEADING TO FAILURE.
LEE, G. 1981	JACKET LEANING.
Chevron, 12/7/61	PILING HAD 20 DEGREE BEND AFTER STORM. CONDUCTOR PIPE WAS CUT LOOSE AND SPRANG ALMOST BACK TO VERTICAL. EARLY ESTIMATES WERE FOR $100,000 TO REPAIR DAMAGE AND STRAIGHTEN STRUCTURE.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 8:59:51

PLATFORM NAME : W. DELTA 117-A
COMPANY NAME : GULF

STORM : BETSY DATE : 09/09/65

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type : TENDER TYPE
Water Depth (ft) : 205
Number of Piles : 8
Number of Wells : 12
Install\Design Date : 07/01/62
Design Criteria : 25-YEAR
Deck Elevation (ft) :
Original Plat. Cost :
Comments : 6 WELLS PRODUCING AT TIME OF STORM. PROD. EQUIP & STORAGE, NO RIG.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
JEFFUS & STONER, '66	MANY OF THE STRUCTURAL BRACES IN THE TOP SECTION WERE EITHER BROKEN OR SPLIT, BUT THE LOWER SECTION OF THE JACKET APPEARED TO BE INTACT.
WORLD OIL, 10/65	THIS PLATFORM PLUS 117-B WERE PRODUCING 3000 BPD. IF GULF CANNOT RECOVER THE 15 WELLS, THEN MONETARY LOSSES WILL BE $10 MILLION.
WORLD OIL, 10/65	TWO WELLS LEAKING.
CHEVRON, 1988	INSTALLATION CONTRACTOR WAS UNABLE TO DRIVE PILING AND CONDUCTORS TO FULL PENETRATION. THE UNDERDRIVEN PILES MAY HAVE INFLUENCED THE FAILURE.
JEFFUS & STONER, '66	SALVAGE WORK REQUIRED MANY DIVERS IN DECOMPRESSION. P&A PLUS SALVAGE TOOK 55 DAYS. THIS INCLUDES 8 DAYS LOST TO WEATHER. SURFACE DIVERS USED FOR 20 DAYS; DECOMPRESSION USED FOR 33 DAYS. THE PLATFORM PIECES WERE SALVAGED AS JUNK.
JEFFUS & STONER, '66	THE DECK SECTION OF THE PLATFORM WAS MISSING AND THE JACKET BENT AT AN 11 DEGREE ANGLE FROM THE M.L. THE ONLY VISIBLE PARTS OF THE PLATFORM ABOVE WATER WERE 2 JACKET LEGS AND A BOAT LANDING.
MMS, 1986	OIL BLOWOUT, CEMENTED. MINIMAL SPILL VOLUME.
CHEVRON, 1988	MINOR SPILL (LESS THAN 238 BBL).

JEFFUS & STONER, '66	TIME REQUIRED TO KILL ALL WELLS AND SURVEY (PLATFORMS A & B) WAS 73 DAYS. THIS INCLUDED 33 DAYS DOWNTIME DUE TO WEATHER AND 6 DAYS DOWNTIME FOR HOLIDAYS.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 9:01:01

PLATFORM NAME : W. DELTA 117-B
COMPANY NAME : GULF

STORM : BETSY DATE : 09/09/65

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: TENDER TYPE
Water Depth (ft)	: 215
Number of Piles	: 8
Number of Wells	: 12
Install\Design Date	:
Design Criteria	: 25-YEAR
Deck Elevation (ft)	:
Original Plat. Cost	:
Comments	: BUILT AS 12 WELLS 9 WERE PRODUCING AT TIME. PROD. EQUIP & STORAGE, NO RIG.

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
WORLD OIL, 10/65	THIS PLATFORM PLUS 117-A WERE PRODUCING 3000 BPD. IF GULF CAN'T RECOVER THE 15 WELLS, THEN MONETARY LOSSES WILL BE $10 MILLION.
JEFFUS & STONER, '66	THE DECK SECTION WITH ALL ITS PRODUCING EQUIPMENT WAS SHEARED OFF AT OR NEAR THE JUNCTION BETWEEN THE DECK AND THE JACKET. THE JACKET WAS TILTED AT 70 DEGREES FROM VERTICAL.
CHEVRON, 1988	APPARENTLY NO BLOWOUTS OR SPILLS.
JEFFUS & STONER, '66	WELLS WERE P&A'D AND CUT DOWN TO M.L. IN 44 DAYS. THE PLATFORM WAS EVENTUALLY CUT UP AND SALVAGED FOR JUNK.

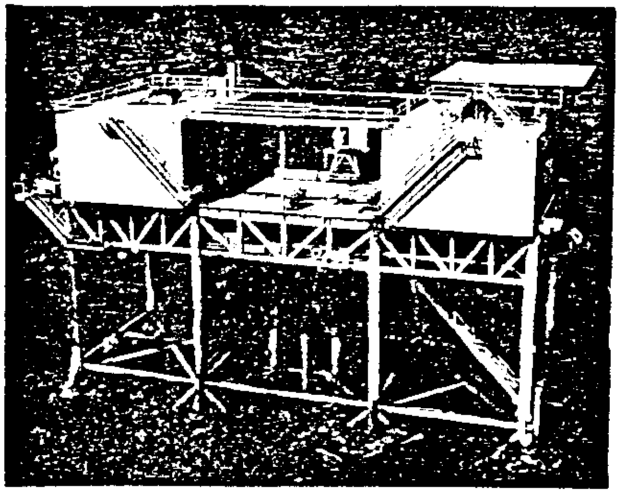


EXHIBIT 2

TYPICAL SIMILAR PLATFORM

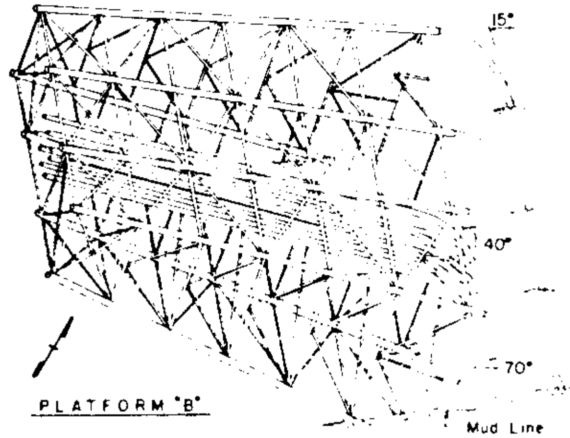


EXHIBIT 17

DAMAGED PLATFORM

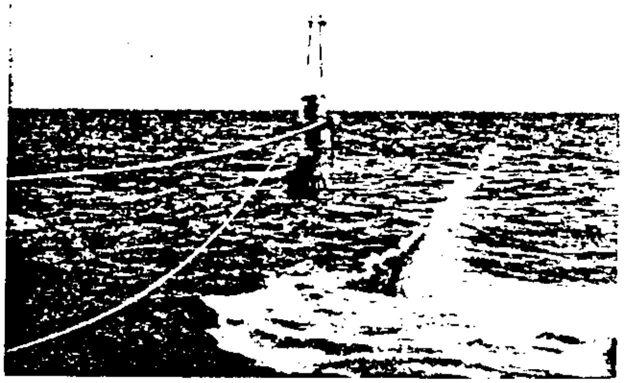


EXHIBIT 9

CAPING WELL

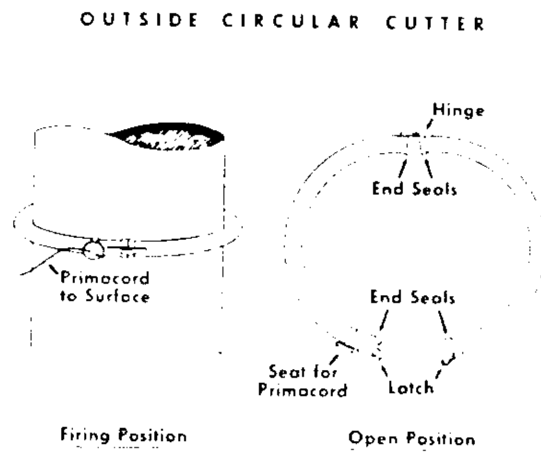


EXHIBIT 21

TUBULER EXPLOSIVE CUTTER

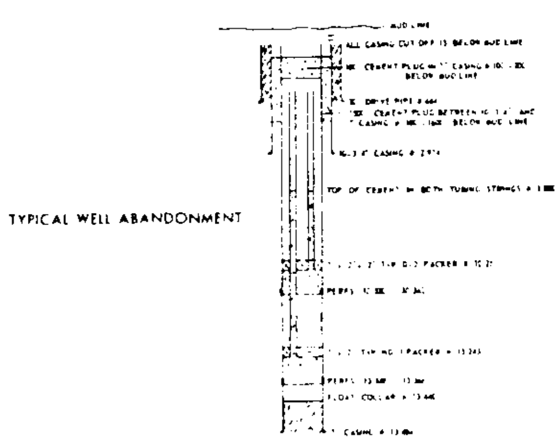


EXHIBIT 22

WELL ABANDONMENT

WEST DELTA 117-B
BETSY

Jeffus, D. M. and Stoner, O. E., "Operation Restoration - West Delta Block 117 Field," Presented at the Fall Meeting of the Society of Petroleum Engineers, Paper Number SPE 1569, Dallas, Texas, October 2-5, 1966.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 9:01:12

PLATFORM NAME : W. DELTA 118
COMPANY NAME : PURE

STORM : BETSY DATE : 09/09/65

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type : TENDER TYPE
Water Depth (ft) : 192
Number of Piles : 4
Number of Wells :
Install\Design Date :
Design Criteria : 25-YEAR
Deck Elevation (ft) :
Original Plat. Cost :
Comments :

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
WORLD OIL, 10/65	PLATFORM EMPTY. ALL 4 WELLS HAD BEEN TEMPORARILY ABANDONED.
LEE, G. 1981	PLATFORM LOST.

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 9:01:27

PLATFORM NAME : W. DELTA 69 #1
COMPANY NAME : CATC

STORM : BETSY DATE : 09/09/65

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: WELL PROTECTOR
Water Depth (ft)	: 125
Number of Piles	: 3
Number of Wells	:
Install\Design Date	:
Design Criteria	: 25-YEAR
Deck Elevation (ft)	: 36
Original Plat. Cost	:
Comments	: TRIPOD WELL PROTECTOR

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1988	COLLAPSE

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 9:02:10

PLATFORM NAME : W. DELTA 70 #3
COMPANY NAME : CATC

STORM : BETSY DATE : 09/09/65

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: WELL PROTECTOR
Water Depth (ft)	: 125
Number of Piles	: 3
Number of Wells	:
Install\Design Date	:
Design Criteria	: 25-YEAR
Deck Elevation (ft)	: 36
Original Plat. Cost	:
Comments	: TRIPOD WELL PROTECTOR

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
LEE, G. 1988	COLLAPSE

---------------- AIM Failure Consequences Database --------------------
---------------- Individual Case Report --------------------

Date : 09/11/88
Time : 9:02:22

PLATFORM NAME : W. DELTA 97
COMPANY NAME : FORREST

STORM : BETSY DATE : 09/09/65

DAMAGE SUMMARY : COLLAPSE

PLATFORM INFORMATION

Platform Type	: TENDER TYPE
Water Depth (ft)	: 167
Number of Piles	: 4
Number of Wells	: 4
Install\Design Date	:
Design Criteria	: 25-YEAR
Deck Elevation (ft)	: 34
Original Plat. Cost	: 0.5 MILL
Comments	:

FAILURE / CONSEQUENCE DETAILED ACCOUNTS

SOURCE	DETAIL
WORLD OIL, 10/65	NO WELLS INVOLVED.

APPENDIX B

USING THE DATA BASE PROGRAM

AIM FAILURE CONSEQUENCES DATABASE PROGRAM

This appendix describes the use of the AIM database program. The program is available in "R:BASE, Version 2.1" or "dBASE III Plus, Version 1.1" formats. The program provides generally the same features when used with either of these database programs. A brief user guide is provided for each.

The R:BASE program was developed during the course of the AIM project to assist in the data gathering. The program was not initially intended for distribution to participants, it was simply a convenient tool to perform the project work. However, based upon participant request, the program was "cleaned-up" and modified for easy use with the intent of distributing a working version to participants. The program was also converted to a dBASE format for several participants. Both forms of the program are provided.

Since delivery of a database program is beyond the original contracted scope of work, maintenance or updating of the program are not provided as part of the AIM III project. You are free to modify the program in any way or form for your own purposes. Refer to the R:BASE or dBASE program manuals for modifications or extensions to the program.

Note that the AIM database program is confidential information for exclusive use of the AIM III participants, per conditions of the AIM III Participation Agreement.

PROGRAM INSTALLATION

The programs should operate on any PC containing R:BASE or dBASE. The program was initially set up for a PC-AT containing a hard disk. Modifications may be necessary for operation directly from a floppy drive. The program and assorted data files are provided on a 360k 5-1/4" floppy.

It is suggested that the information be installed on a hard disk in a special directory (e.g AIM). The PATH for this directory must be able to linked to the master R:BASE or dBASE files. Log into this directory and insert the floppy into the floppy drive.

For installing the R:BASE files type: "COPY A:\RBASE" after the DOS prompt and hit "Enter." The files will then be copied into the directory. Note that this command assumes the floppy is being read from drive "A." Substitute the appropriate drive (e.g. "B") for your machine.

For installing the dBASE files type: "COPY A:\DBASE" after the DOS prompt and hit "Enter."

The AIM Failure Consequences Database and Menu driven data query system is now installed. Simply type "AIM" to access the program and data files. A brief user guide is provided for both R:BASE and dBASE. Good Luck!

AIM FAILURE CONSEQUENCES DATABASE - dBASE III PLUS VERSION

USER GUIDE

To start the program type "AIM" at the DOS prompt. The dBASE main program will first load and display a LOGO screen. You may either wait 5 seconds for the logo to disappear or hit ENTER. The AIM Main Menu is then displayed. The operation of each main menu item is briefly discussed below.

The information in the database is case sensitive. You must always use capital letters. It is best to use the "CapsLock" key at the beginning of the session to ensure you are always using capitals.

0. EXIT TO DOS. Select "0" and hit Enter to exit the AIM program and dBASE and return to DOS. This is the default selection.

1. NEW DATA ENTRY. Select "1" and hit "Enter" to access this option which appends new data onto the database. New data can be some more information on a platform currently in the database or a new platform failure. The key identifier in the database is the Platform Name. So if you are adding new data (generally a new "Source" and "Detailed Account") for a platform already in the database, key in the exact platform name as it appeared before, and add the new source and detailed account. To make revisions to the other data for an existing platform (such as number of piles), you need to use Option 2.

Once you are done defining data, press "Esc" to return to the Main Menu.

2. MODIFY EXISTING DATA. Select "2" and hit "Enter" to access this option which allows you to modify or add information related to a specific platform. The program will then prompt you for a "unique" keyword in the platform name such as "70-B" for South Pass 70-B. Alternatively, you can input the complete platform name as shown on the master platform list at the beginning of Appendix A. Then hit "Enter" to modify the data.

Each database record related to the platform is then displayed on the screen. The entire record (i.e. storm, date, number of piles, etc.) is repeated for each "Source" and "Detailed Account." Thus to change data related to the storm or platform configuration, it should be changed on every record for the platform. However, the "Source" and "Detailed Account" should be different for each record.

The screen displays the first record in the database for the platform. You may edit the record in any way. The arrow keys move the cursor within the record. Note that the "Comments" and "Detailed Account" fields are only partially shown and will scroll to the left when the cursor gets to the end of the screen. PgDn moves to the next record or quits the session if you are on the last record. PgUp moves to the previous record or quits the session if you are on the first record. Ctrl-End exits and saves all changes. Esc exits and abandons changes to the current record.

3. DATA QUERY. Select "3" and hit enter to access this option which allows you to query the database. A new menu will prompt for the basis of data query - Company, Storm, Platform (Location), and Consequence. Once you select a choice, the program will prompt for further data such as Storm Name (e.g. Hilda). Insert your choice and press Enter.

The program will then ask if you want the results sent to the printer as well as the screen. Choose Y to print the results or N for screen viewing only. Note that if you do not have a printer connected to the PC you may "lock" the system, requiring you to "re-boot" your computer. The dBASE main program may catch this error and issue you a warning, respond with I for Ignore to continue operation.

For the Consequences Query, input a keyword (e.g. Blowout, Salvage) for the program to search for in all Detailed Accounts. For this option, the program may list more than one account for any platform.

The list generated by the program will be blank if your query item does not exist in the database. For long lists, the data will scroll to several screens. Hit Pause to stop scrolling (or printing). Hit Enter to continue.

Once you are done with a Data Query, Select 0 to return to the Main Menu.

4. REPORT GENERATION. Select "4" and hit Enter to access this option which allows you to view on screen or print summary or individual case reports. A new menu appears with this option asking for the type of report to be generated. These are similar to the tables that appear in the body of this report. Note that the tables used in the report were generated using R:BASE and have a slightly different format than the tables generated by dBASE.

Database Summary Report (Menu Item 1) lists all of the information in the database sorted according to your choice. The program will ask for your selection (Storm, Company, etc.). Input the noted number (e.g 1 for Storm) and hit Enter. The program then asks if you want the information sent to the printer. Select Y if you desire a printed report. As previously noted, only ask for the print option when a printer is hooked to your PC.

Individual Case Report (Menu Item 2) lists all of the information about a particular platform. The program will prompt for the name of the platform. Only a unique identifier is required (e.g. 70-B). Again you are asked if you desire to print the results. For this option, only a portion of the report is shown on the screen when you select Y for print.

Select "0" to return to the Main Menu.

5. EXIT TO DBASE. Select "5" and press Enter to access this option. This allows you to exit the AIM program and return to the dBASE main program which is identified with a "." (dot) prompt. Type DO AIM to return back to the AIM program. Alternatively, hit Esc to toggle between the dot prompt and the menu driven dBASE main program. This is the location for making modifications to the AIM program (file name AIM.PRG), input screens and reports.

AIM FAILURE CONSEQUENCES DATABASE - R:BASE VERSION

USER GUIDE

To start the program type "AIM" at the DOS prompt. The AIM Main Menu is then displayed. The operation of each main menu item is briefly discussed below.

1. NEW DATA ENTRY. Select "1" and hit "Enter" to access this option which appends new data onto the database. New data can be some more information on a platform currently in the database or a new platform failure. The key identifier in the database is the Platform Name. So if you are adding new data (generally a new "Source" and "Detailed Account") for a platform already in the database, key in the exact platform name as it appeared before, and add the new source and detailed account. To make revisions to the other data for an existing platform (such as number of piles), you need to use Option 2. Option 2 is also an easier way to add new data related to a platform already in the database.

Once you are done defining data, press "Esc" to return to the Main Menu.

2. MODIFY EXISTING DATA. Select "2" and hit "Enter" to access this option which allows you to modify or add information related to a specific platform. The program will then prompt you for a "unique" keyword in the platform name such as "70-B" for South Pass 70-B. Alternatively, you can input the complete platform name as shown on the master platform list at the beginning of Appendix A. Then hit "Enter" to modify the data.

You have now entered the R:BASE Edit Command Module. Each database record related to the platform is then available for editing. The R:BASE Edit functions displayed on top of the screen. Select Edit to modify the file. The arrow keys move the cursor within the record. Note that the "Detailed Account" field is only partially shown and will scroll downward to accept more data. Press Esc when you are done and the Editing menu will reappear.

The entire record (i.e. storm, date, number of piles, etc.) is repeated for each "Source" and "Detailed Account." Thus to change data related to the storm or platform configuration, it should be changed on every record for the platform. However, the "Source" and "Detailed Account" should be different for each record.

Use the Next and Previous options in the menu to move between records. Delete erases a particular record. Add New saves the current record as a new record but retains the original record without changes. As previously noted, the Add New option can be used to add new data about a platform. Simply add a new record and then modify the record with your new information. This way you do not have to re-enter information such as number of piles, water depth, storm, etc. Reset restores a record to its state original state prior to editing. Save stores the changes that have been made and should be used after each Edit. Quit returns you to the AIM Main Menu. For further discussion of these commands see the R:BASE manual under the term "EDIT."

3. DATA QUERY. Select "3" and hit enter to access this option which allows you to query the database. A new menu will prompt for the basis of data query - Company, Storm, Platform (Location), and Consequence. Once you select a choice, the program will prompt for further data such as Storm Name (e.g. Hilda). Insert your choice and press Enter.

The program will then ask if you want the results sent to the printer as well as the screen. Choose Y to print the results or N for screen viewing only. The print format for this option requires you to manually advance your printer to the next page after printing. Note that if you do not have a printer connected to the PC you may "lock" the system, requiring you to "re-boot" your computer.

For the Consequences Query, input a keyword (e.g. Blowout, Salvage) for the program to search for in all Detailed Accounts. For this option, the program may list more than one account for any platform.

The R:BASE program will issue a message if your query item does not exist in the database. For long lists, the data will scroll to several screens. Hit Pause to stop scrolling (or printing). Hit Enter to continue.

Once you are done with a Data Query, Select 5 to return to the Main Menu.

4. REPORT GENERATION. Select "4" and hit Enter to access this option which allows you to view on screen or print summary or individual case reports. A new menu appears with this option asking for the type of report to be generated. These are similar to the tables that appear in the body of this report. You must manually advance the printer to the top of the next page after each print.

Database Summary Report (Menu Item 1) lists all of the information in the database sorted according to your choice. The program will ask for your selection (Storm, Company, etc.). Input the word exactly as shown on scree (e.g. Storm) and hit Enter. The program then asks if you want the information sent to the printer. Select Y if you desire a printed report. As previously noted, only ask for the print option when a printer is hooked to your PC.

Individual Case Report (Menu Item 2) lists all of the information about a particular platform. The program will prompt for the name of the platform. Only a unique identifier is required (e.g. 70-B). Again you are asked if you desire to print the results.

Select "3" to return to the Main Menu.

5. EXIT TO R:BASE. Select "5" and press Enter to access this option. This allows you to exit the AIM program and return to the dBASE main program which is identified with a "R" prompt. Type RUN AIM to return back to the AIM program. Alternatively, hit Esc to toggle between the dot prompt and the menu driven R:BASE main program. This is the location for making modifications to the AIM program (file name AIM), input screens and reports.

6. EXIT TO DOS. Select "6" and hit Enter to exit the AIM program and dBASE and return to DOS.

APPENDIX C

FAILURE DATA BASE REFERENCES

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DEVELOPMENT OF GUIDELINES FOR
EVALUATIONS AND JUSTIFICATIONS
OF SUITABILITY FOR SERVICE

AIM III

FINAL REPORT NO. 3

BY

PMB SYSTEMS ENGINEERING INC.

SAN FRANCISCO, CA

SEPTEMBER 1988

APPLICATIONS

This report addresses an approach for making and communicating evaluations of the suitability for service of existing platforms. This approach is not intended for application to designs of new platforms. Accepted current engineering guidelines (e.g. API RP 2A) should be used for design of new platforms.

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LIST OF SYMBOLS

α	Wave Height Exponent Used to Determine Total Lateral Force (Due to Wind, Wave and Current)
A	Activity Factor
B	Safety Index (Annual)
B_m	Marginal Safety Index
B_o	Optimum or Lowest Total Cost Safety Index
C	Consequences of Loss of Serviceability Measure
COV	Coefficient of Variation
CR	Cost Ratio: Ratio of the Expected Cost of the Platform Loss of Serviceability to the Cost Needed to Decrease the Annual Likelihood of Platform Loss of Serviceability by a Factor of 10.
ϵ	Calculation Error = Measured or True Quantity/Predicted or Calculated Quantity
$\exp(\bullet)$	Exponential Function $e^{(\bullet)}$
$\hat{F}$	Median Annual Expected Maximum Total Force
F_m	Maximum Total Lateral Forces on the Platform
F_r	Reference Force: Minimum Force Suggested by Current Guidelines or Requirements (e.g. API RP 2A Gulf of Mexico Reference Level Wave Heights and Forces)
FR	Force Ratio = F/F_r
GOM	Gulf of Mexico
$\overline{H}$	Mean Annual Expected Maximum Wave Height

LIST OF SYMBOLS, Cont.

$\hat{H}$	Median Annual Expected Maximum Wave Height
H_m	Expected Annual Maximum Wave Height
K	Platform Force Coefficient
L	AIM Cycle Period (Years)
N	Expected Maximum Number of People Exposed to Risk
P_{fa}	Annual Likelihood of Loss of Platform Serviceability (Failure)
PVF	Present Value Function
$\hat{R}$	Median (50th Percentile) Capacity
R_c	Ultimate Limit State Strength or Load Capacity
RP_c	Return Period (Years) Associated with the Expected Annual Maximum Loading that Brings the Platform to Its Ultimate Limit State
RSR	Reserve Strength Ratio
SSSV	Sub-Surface Safety Valve
T	Platform Life (Years)
U	Uncertainty Measure: Standard Division of Natural Logs of Force and Capacity Distributions
U_f	Force Uncertainty Measure
U_h	Annual Expected Maximum Wave Height Uncertainty Measure
ULS	Ultimate Limit State
U_r	Capacity Uncertainty Measure

LIST OF SYMBOLS, Cont.

V	COV
V_{cf}	COV of Force Calculations
V_{cr}	COV of Capacity Calculations
V_f	COV of Forces
V_r	COV of Resistances

1.0 INTRODUCTION

During the AIM-I Project, two general and complimentary categories of approaches were explored for evaluating and justifying AIM programs for existing offshore platforms [1]. These were:

1. Commercial-industrial, cost-utility-benefit approaches; and
2. Public-regulatory, calibration-standard of practice approaches.

The first category was based on the premise of identifying AIM programs that would minimize total costs (initial and future) associated with requalifications (Figure 1-1). Alternatively, this approach could be focused on maximizing utilities, where utilities are nondimensional measures of initial and future potential impacts.

The second category was based on the premise of identifying AIM programs that would preserve essential reliability and safety (property, resource, life, environment) objectives that were determined from historical data, and references to present standards of practice (for design and requalifications of structures (Figure 1-2).

During the AIM-II project, two Gulf of Mexico platforms were studied to test the basic AIM approach [2]. These were early generation platforms (1950 to 1960) that had a variety of defects. In addition, the platforms were low-consequence structures that were unmanned and posed no significant environmental or pollution threats.

Both the commercial cost-benefit and calibration-standard of practice approaches were used to evaluate the example platforms. The two approaches developed comparable results.

The AIM Participants felt that a simplified and practical engineering approach should be developed for making evaluations of platform AIM programs (suitability for service), with particular emphasis on the public-regulatory aspects. Further, the participants felt that the approach should be one that would facilitate communications with non-experts and non-engineers, and would embody meaningful measures of the key elements involved in developing judgements of platform AIM program Suitability for Service (AIM-SS).

It was not an objective of this effort to develop specific guidelines, rules, or regulations for judging suitability for service of existing offshore platforms. Rather, it was an objective to outline and illustrate a general approach that could be used to facilitate such developments.

It is important to recognize that the focus of the AIM-SS approach is on requalification of existing, older platforms whose original design criteria have now become obsolete, that are defective, or that have experienced damage during their service lives. Design criteria for new platforms involve similar, but not the same issues and evaluations.

The problems associated with determining suitability for service of a major platform with potentially significant defects is one that should be approached without rigid conformance to conventional practice. The basic objective is to maintain a high level of technical and operating excellence by defining creative and practical ways to increase reliability and serviceability within the unavoidable constraints of currently available knowledge, manpower, money, and time. This is a structure and problem specific approach. It is not an engineering code or rigid guideline approach.

When viewed in the context of making the best decision on a current AIM program, what must be the common industrial and public objective of doing the "right thing" should be recognized. The right thing consists of making warranted investments in expectation of equitable benefits, and making progress in development of a much needed resource while minimizing negative effects or impacts. The AIM-SS approach challenge is to foster a process to examine and communicate acceptability for service from these viewpoints.

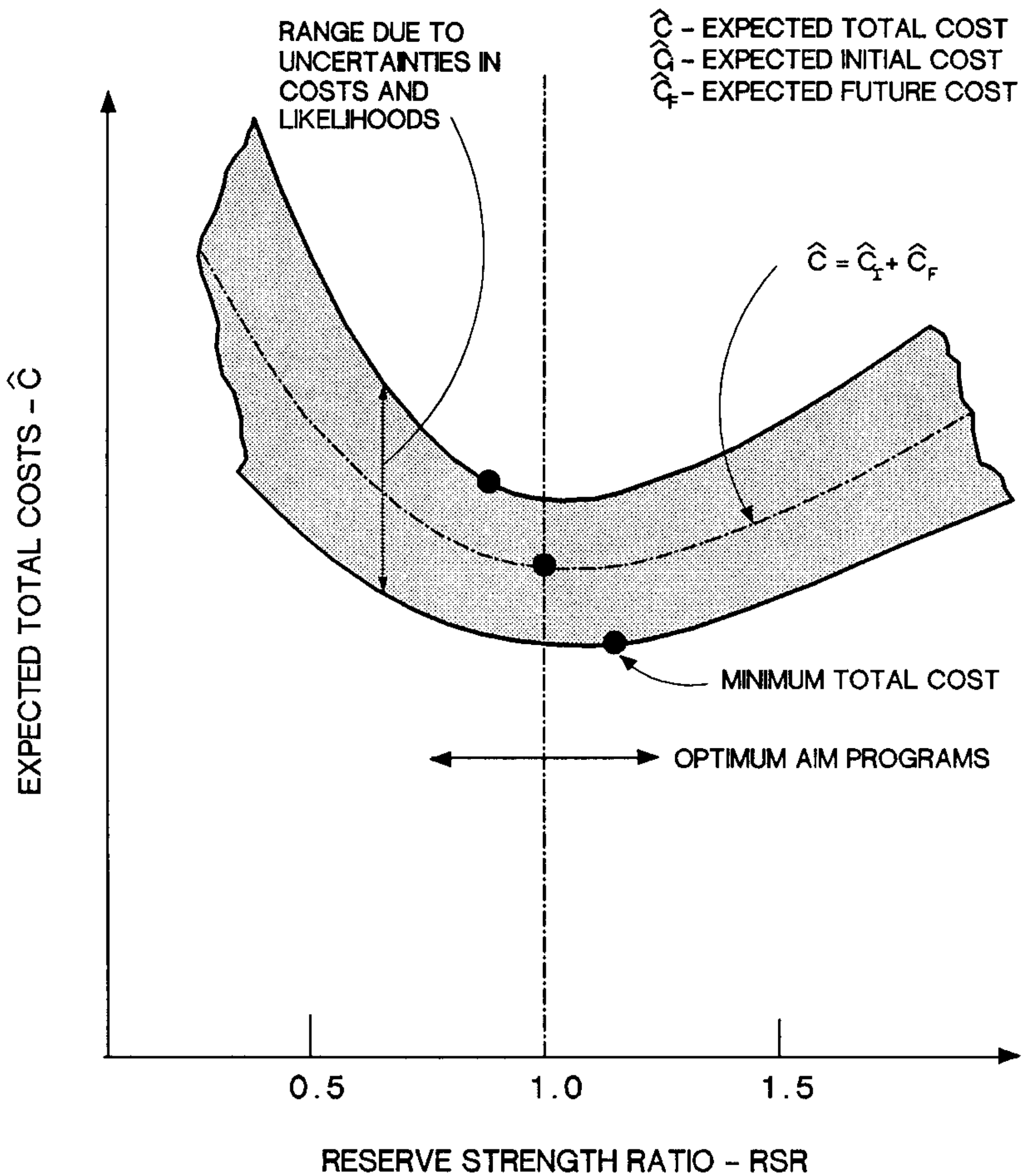


Figure 1-1 Example Commercial-Industrial Cost-Utility-Benefit Evaluation

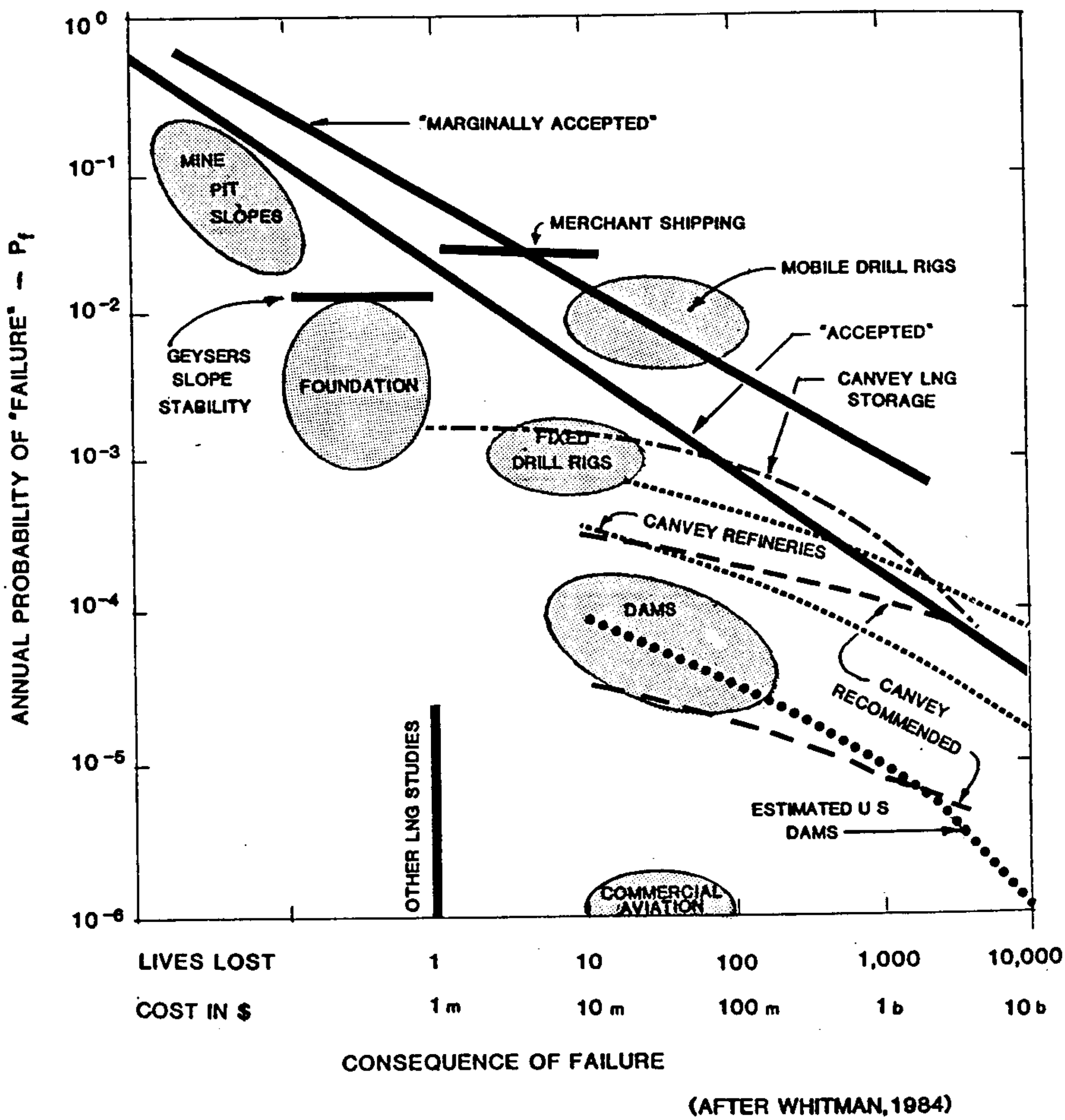


Figure 1-2 Public-Regulatory Calibration-Standard of Practice Evaluation

2.0 PUBLIC-REGULATORY ENVIRONMENT

In the public-regulatory environment, a basic concern is with the safety aspects of platform AIM programs:

"The lessee shall design, fabricate, install, use, inspect, and maintain all platforms and structures (platforms) on the Outer Continental Shelf (OCS) to assure their structural integrity for the safe conduct of drilling, workover, and production operations, considering the specific environmental conditions at the platform location." [3]

"The safety of life and property depends upon the ability of the structure to support the loads for which it was designed and to survive the environmental conditions which may occur. Over and above this overall concept, good practice dictates use of certain structural additions, equipment, and procedures on a platform so that injuries to personnel will be minimized and the risk of collision from ships reduced. Governmental regulations stipulating such requirements listed in Section 1.8 and all other applicable regulations should be carried out." [4]

As pointed out in discussion of this report (refer to Appendix A, letter from Spencer), the safety of people and protection of property, resources, and the environment are social concerns that regulatory bodies must address in the light of specific authorities in federal and state laws.

Social and political negative impacts can go far beyond a single event of loss of life or property, or serious pollution of the environment. The response to such events as the Union blowout in the Santa Barbara Channel, and the failure of the Odeco platforms during Hurricane Juan indicates the potentially far-reaching ramifications of public and regulatory response intended to prevent future problems of a similar nature.

The public-regulatory safety concerns center primarily on environmental, resource, and life protections. The industrial concern is with these same safety aspects, and in addition, the property and cost-economic aspects.

Utilities and weightings of the safety aspects and protections may differ from party to party, group to group, and time to time; and it is here, that some general procedures or approaches are needed to assist justifications and communications of suitability for service in the public-regulatory environment.

An objective of the AIM-SS approach is to be able to clearly and consistently evaluate platform AIM programs in a simple framework allowing equitable and efficient comparisons and allocations of resources. A second objective is to facilitate communications between the wide variety of backgrounds and responsibilities inherent in the groups involved in developing, implementing, and approving platform AIM programs.

3.0 SUITABILITY FOR SERVICE FORMAT

During the AIM II project [2], a general format for illustrating and expressing platform AIM program suitability for service evolved (Figure 3-1). This format expresses the safety-strength (capacity) aspects of the platform through a Reserve Strength Ratio (RSR, Figure 3-2). The AIM-SS format expresses the range of potential consequences associated with a particular platform and its AIM program in three broad categories. The suitable for service range is separated from the unsuitable for service range by a zone. The boundaries of this zone are indicated by two lines labeled "acceptable" and "marginal".

3.1 Reserve Strength Ratio

The platform Ultimate Limit State (ULS) capacity (load resistance) is expressed with the RSR. The ULS capacity is defined as the state that results in structural collapse or damage of such an extent that the structure is rendered unusable (loss of structural integrity). The state that results in loss of serviceability can be termed "failure".

In the context of the RSR, the ULS capacity can be characterized by a static push-over (or limit equilibrium) type of analysis [1,2,5,6,7]. In such analyses, a loading pattern (or patterns) representing the maximum loading effects of concern are placed on the structural system (Figure 3-2), and these loading effects increased to the point at which the structure fails (e.g. loss of equilibrium under the lateral and vertical loadings).

Such analyses have been used extensively in "two-level" earthquake guidelines for design of platforms in seismic regions [3,4]. The first level of ground motions (Strength) are used to size the platform elements (generally based on linear elastic procedures). The second level of ground motions (Ductility) are used to verify that the platform possesses the necessary "robustness" (combination of capacity, ductility, and redundancy).

Given such an analysis context, the RSR can be defined as follows:

$$\mathrm{RSR} = \frac{R_c}{F_r} \tag{1}$$

where R_c is the ULS strength or load capacity of the platform maintained or rehabilitated with a given AIM program.

The reference force, F_r, would generally be taken as the minimum force implied or suggested by current accepted guidelines or requirements for design of an equivalent new structure. In the Gulf of Mexico (GOM), F_r could be the "100-year" maximum total lateral force associated with API RP 2A's Design Guideline Wave Heights (Figure 3-3) and Reference Level Wave Forces (Figure 3-4) [4].

Thus, the RSR is an index reflecting the platform's capacity (established by a given AIM program, and based on a static push-over analysis) relative to the minimum current level of force that would be used to design an equivalent new platform. Note that the RSR can be less than, equal to, or greater than one.

For a large number of Gulf of Mexico platforms designed before 1970, it is possible that the RSR is one or less. Many of the first generation platforms designed with "25-year" criteria, would have RSR's of the order of 0.5. The AIM III study has indicated RSR's for a nondefective early 1970 conventional 8-pile platform to be in about 1.5.

The studies reported by Titus and Banon [5], Lloyd and Clawson [6] and Nordal [7] indicate RSR's for platforms designed by current guidelines to be in the range of 2.0. Based on current design guidelines and static push-over analyses, platforms designed for locations in which earthquakes control or dominate the design forces commonly have RSR's in the range of 2 or more [8,9].

The RSR should be viewed not as a single number, but as the best estimate within a given range of potential RSR's [10,11]. This is due to the uncertainties and variabilities that are associated with analytical evaluations of the performance of elements (joints, braces, legs, piles, as is, repaired, etc.) and a system of elements (the platform) [12].

It should be understood that the RSR is an index for comparing a type of analytical evaluation of ultimate limit state (ULS) capacities of platforms (e.g. based on static push-over analyses and static behavior of elements). In general, the true ULS capacity can not be directly or easily equated with the capacity used to define the RSR. The RSR is intended to provide a practical, yet realistic, basis on which to compare platform AIM programs and make judgements concerning suitability for service.

Another important aspect of the RSR pertains to the reference force, F_r. This reference force is intended to reflect present-day consensus on what force should be used to design an equivalent new platform. There are two critical aspects imbedded in F_r. The first is the basis for determination of the force; the basis is intended to represent a minimum level of force that the "community" (consensus of engineers, operators, owners, regulators) deems prudent for design of equivalent new platforms.

The second is that the basis for design presumed is the present Working Stress Design (WSD) guidelines of API RP 2A [4]. Structural analyses founded primarily on linear elastic methods are the basis of these guidelines. Other bases for design (e.g. Limit State and Load and Resistance Factor formats) will need to be carefully interpreted to be consistent with the basis for the reference force used in the AIM-SS development.

Care must be taken when interpreting RSR's when the reference forces are based on site-specific wave heights and surges that bring the wave crests to the deck level. Small errors in the wave crest elevations could have dramatic effects in increasing the reference force, and in decreasing the RSR.

The reference force can be modified by the operator of AIM programs. Removal of unnecessary elements in the platform (e.g. unused conductors, boat landings, etc.) and marine growth removal can be used to reduce the area projected to intense wave and current action and reduce the associated drag forces. Thus, when the reference level force is determined, recognition can be given to the benefits from such AIM measures.

There are other possibilities for reducing the reference forces, particularly in earthquake hazard areas (e.g. weight reductions) and ice loading hazard areas (e.g. passive and active ice management or defense measures).

3.2 Consequence Categories

The AIM-SS format expresses the safety, environmental, resource, life, and property protection aspects through three general categories of consequences in the event of a platform's loss of serviceability ("failure").

A Low Consequence category (Category 1) would be a platform and its AIM program that would pose no or little risks to the environment, resource (hydrocarbon reserves), life, or property.

A High Consequence category (Category 3) would be a platform and its AIM program that would pose significant or major risks to the environment, resource, life, or property. Platforms that supported a large drilling and production operation and that were manned with a large number of personnel during extreme environmental events (storms, earthquakes, severe ice loadings) could be placed in this category.

A Moderate Consequence Category (Category 2) would be a platform and its AIM program that would pose hazards to the environment, resource, or life that fall in between these two extremes. Manned platforms that were evacuated in advance of extreme environmental events could be placed in this category.

It is very important to note that the platform owner/operator and offshore platform design and operations regulations-guidelines [3,4] can exert significant influences on the categories of consequences, given a platform's loss of serviceability. Evacuation and life saving training and equipment are examples of operator controls placed on potential injury consequences. Down-hole, subsurface and surface emergency shut-in and well control safety equipment are examples of operator controls placed on potential resource and environmental consequences. Pollution control and abatement measures are examples of operator controls placed on potential environmental consequences. The timing and extent of inspection and requalification AIM cycles (and associated repairs or strengthening measures) are examples of operator controls placed on potential property consequences.

Documentation of the consequences of 36 major Gulf of Mexico platform losses of serviceability during hurricanes and associated events (e.g. mudslides, collisions) indicates that the major consequences have been isolated to property losses [13]. There has not been a single loss of life, due primarily to the Gulf of Mexico practice of evacuating platforms in advance of intense hurricanes. There has been only one major well blowout among some 140 wells affected by hurricane related structure losses of serviceability. Of these 140 wells, less than 5 percent have leaked minor amounts of hydrocarbons. There has been no significant negative environmental impacts associated with any of these failures [13].

This experience indicates that for the vast majority of older GOM platforms, potential consequences should fall in the low to moderate categories (Categories 1 and 2), and be restricted principally to property losses. This is particularly true in the light of operator provisions for evacuation and life saving, well control and shut-in, and pollution control and abatement.

Platforms offshore California and Alaska (Cook Inlet) could be manned during intense environmental events (earthquakes, severe ice loadings), and thus involve potential injuries in the event of loss of platform serviceability. These platforms are also located in sensitive environmental areas; thus, there would be concerns for potential negative environmental impacts in the event of loss of platform serviceability. Depending primarily on the operator measures to control potential consequences, such hazards could place these structures in a category of moderate to high potential consequences (Categories 2 or 3).

Thus, the AIM-SS format expresses the capacity of a platform (established by a proposed AIM program) through the RSR index and relates this capacity to three general categories of potential consequences (that are also influenced by a proposed AIM program). Within reasonable ranges, both of these variables can be altered by operator actions in managing the loadings on, capacities of, knowledge of, and potential consequences associated with a given platform.

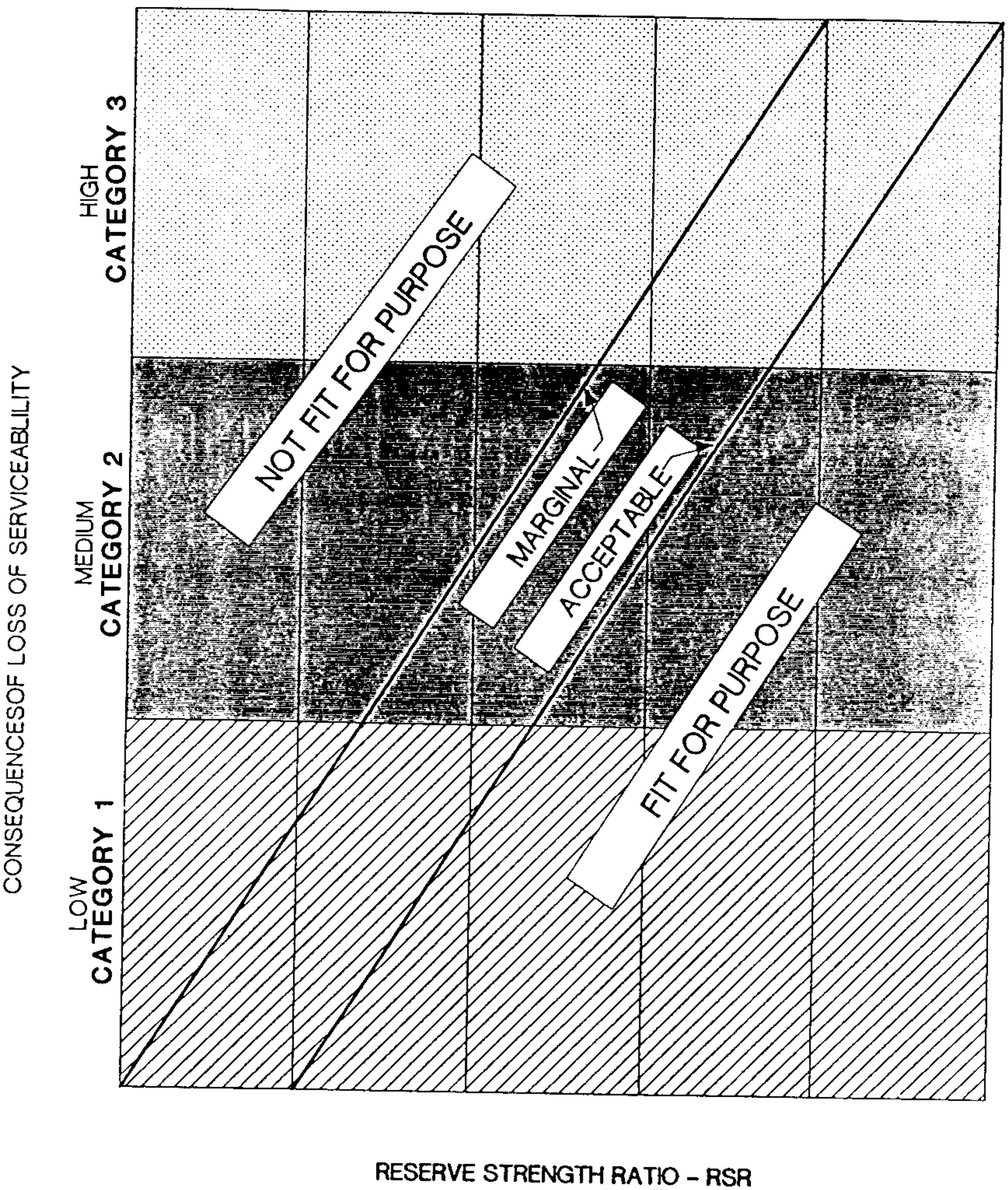


Figure 3-1 **AIM Program Evaluation of Suitability for Service Format - AIM-SS**

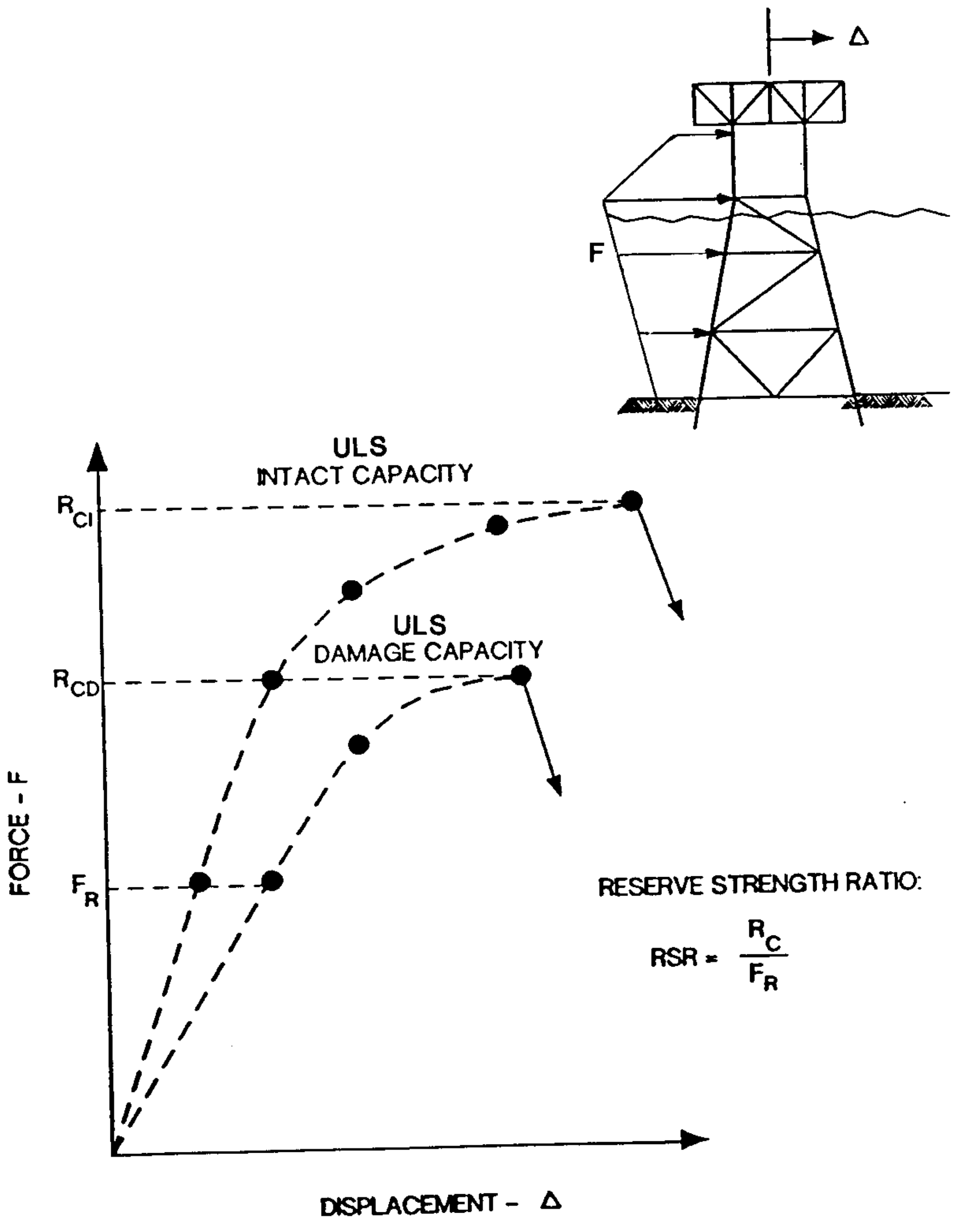


Figure 3-2 **Determination of the Reserve Strength Ratio (RSR) from Push-Over Analyses**

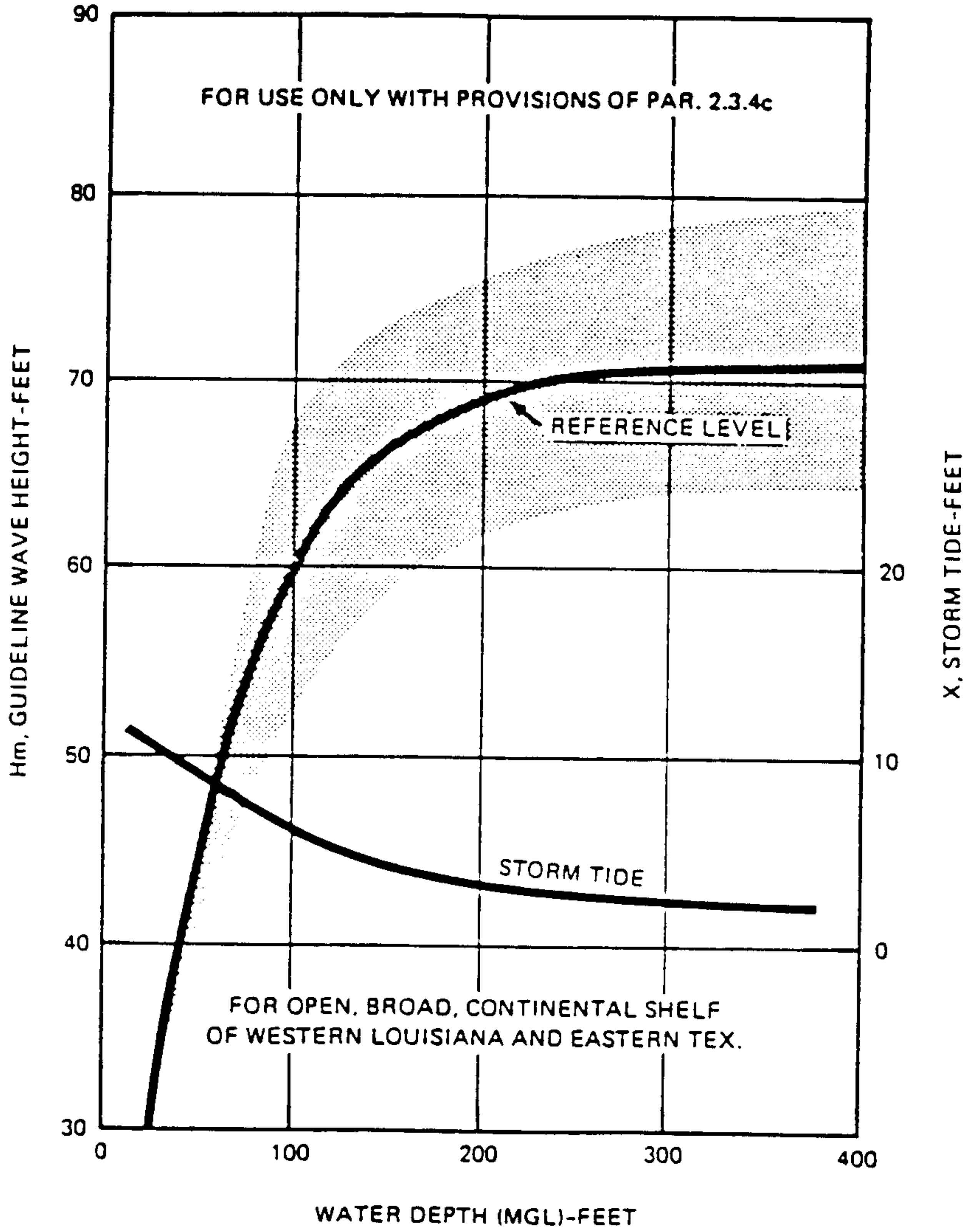


Figure 3-3 **American Petroleum Institute (API) Guideline Wave Heights for the Gulf of Mexico**

2.3.4g. Forces. The reference level wave heights, storm tides, and wind speeds should be applied in the calculation of reference level forces with a specific combination of other provisions of this section and those of Sections 2.3.1 and 2.3.2. These reference level wave forces should be computed using the Morison equation (2.3.1-1), the full projected area of all structural members and appurtenances in the wave zone, a constant drag coefficient of 0.6, an inertia coefficient of 1.5 for members six feet in diameter or less, increasing linearly to 2.0 for members ten feet in diameter and greater, the appropriate wave theory as specified in Section 2.3.1, a wave period based on the wave steepnesses as specified in Table 2.3.4-1, and appropriate allowances for marine growth as discussed in Sections 1.3.10 and 2.3.1. The reference level wind force should be calculated as described in Section 2.3.2.

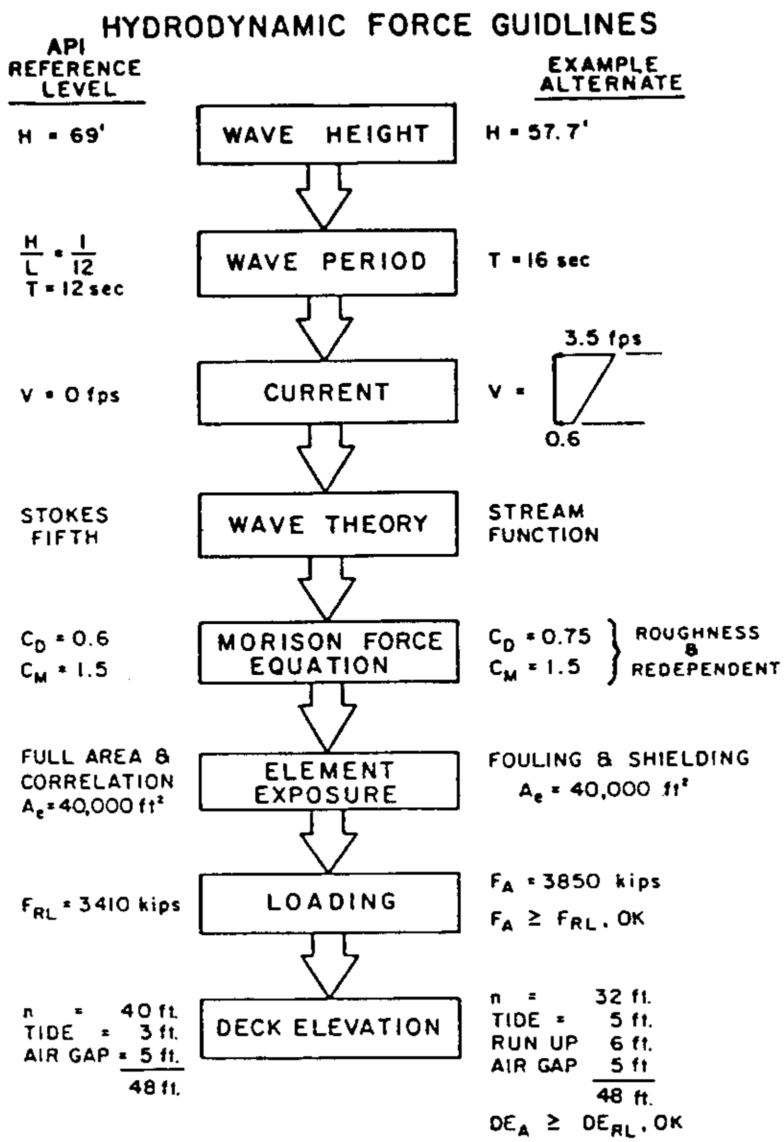


Figure 3-4 API Reference Level Wave Force Guidelines and Application Illustration

4.0 EVALUATION OF SUITABILITY FOR SERVICE

Given measures of platform capacity and potential consequences associated with a given AIM program, the next challenge is to develop qualitative and quantitative evaluations that will facilitate evaluations of platform suitability for service. This is equivalent to developing information to answer the question: given a proposed AIM program for a platform, does the program develop a reasonable balance of strength (capacity) and potential consequences?

In the AIM-SS format (Figure 3-1), this question is addressed by defining a region that separates those combinations of strength and potential consequences that are clearly acceptable (suitable for service), and those that are not (unsuitable for service). Note that the critical line is labeled "marginal." The following paragraphs will outline an analytical framework to relate RSR's and the categories of potential consequences.

This development will be separated into two parts. The first part will relate the platform RSR to the likelihood of the platform loss of serviceability. The second part will relate the likelihood of platform loss of serviceability to the categories of potential consequences. The result will be the relationship of RSR to potential consequences.

Further, uncertainties in the evaluations of measures of loading conditions (e.g. maximum wave heights, peak ground velocities) and the translation of these loading conditions to forces or force effects can be entered into the characterizations of return periods (a measure of uncertainty) associated with the maximum loadings [10,11]. It is advisable to determine P_f with and without these uncertainties so that the effects of potential improvements in the evaluations of conditions and forces can be understood.

A numerical example will help to clarify these developments. In AIM-III, it was found that platform "C" had a reference force, F_r = 1630 kips (API minimum). The site and platform specific oceanographic-hydrodynamic study indicated a median annual expected maximum force, $\hat{F}$ = 280 kips (Figure 4-1). Thus, FR = 0.17.

The probability distribution of forces indicates a Standard Deviation of the Log of total forces, U_f = 0.74. As will be described later, if the additional uncertainties due to platform capacities [7,12] are considered (U_R = 0.25), U_f = 0.78. If it is presumed that the acceptable B = 2.5 (annual), then equation (2) indicates an acceptable RSR = 1.2.

Platform "C" had an RSR of about 1.6 (Figure 4-2). Given the presumed B, platform "C" has an acceptable RSR.

4.2 Force Ratio and Uncertainty Measure

Two other factors in equation (2) merit further development and discussion: the Force Ratio, FR, and the uncertainty measure, U.

If it assumed that the maximum total lateral forces developed on the platform, F_m, are a function of the expected maximum wave height, H_m, raised to an exponent, α, then [11]:

$$F_m = K \; H_m^a \tag{6}$$

where K is a factor that is determined by the platform and wave characteristics.

Further, if it is assumed that the expected annual maximum wave heights at the platform site are Lognormally distributed with a mean height, $\hat{H}$, and Standard Deviation, U_h, and that the reference force, F_r, is defined at the 100-year Return Period condition, then the Force Ratio can be expressed as:

$$FR = \exp(-2.33 a U_h) \tag{7}$$

where V_h is the Coefficient of Variation (COV) of the expected annual maximum wave heights:

$$V_h = \frac{U_h}{\overline{H}} \tag{8.1}$$

where $\overline{H}$ is the mean annual expected maximum wave height. The median and mean annual expected maximum wave heights are related as follows:

$$\overline{H} = \hat{H} \exp\left(\frac{V_H^2}{2}\right) \tag{8.2}$$

For example, AIM platform "C" had a V_h = 0.38, α = 2.0, and an estimated V_{cf} = 0.30 (Figure 4-6). From equation (10), V_f = 0.82. Based on previous analyses [10,11,12], V_r is estimated to be 0.3 (Figure 4-7).

From equations (9) and (12), the uncertainty measure, U = 0.77.

Thus, we can see that the RSR can be related with indices of platform likelihood of loss of serviceability (P_f or B) and uncertainties in the demands (loads) and capacities (resistances) of a platform. Next, measures of likelihood of loss of serviceability will be related to ranges of potential consequences associated with the loss of serviceability.

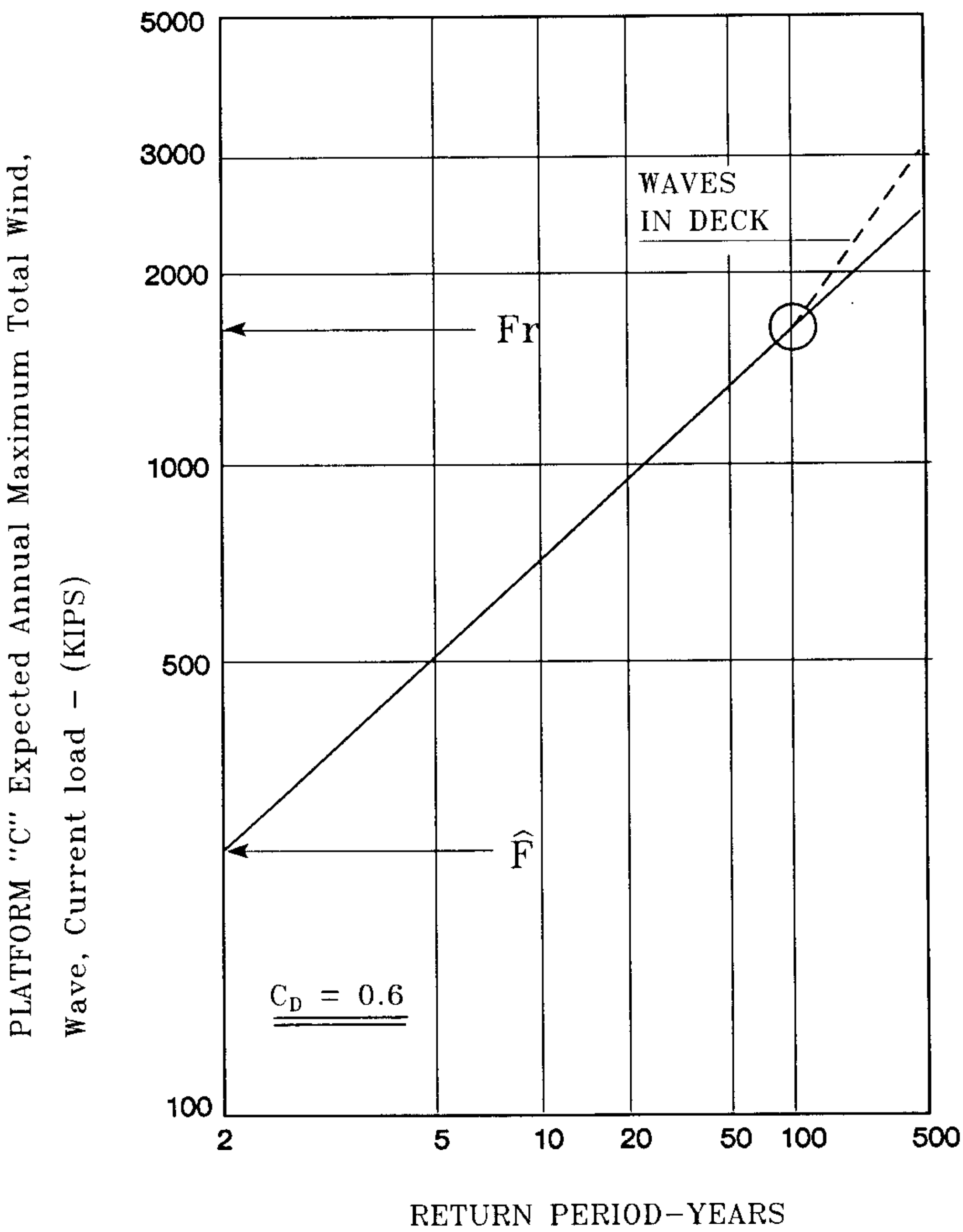


Figure 4-1 AIM III Platform "C" Hurricane Maximum Total Lateral Loadings (End-On) and Return Periods

AIM 03B345
FL/DISK.001
/AIM/CHRTS
FIG07

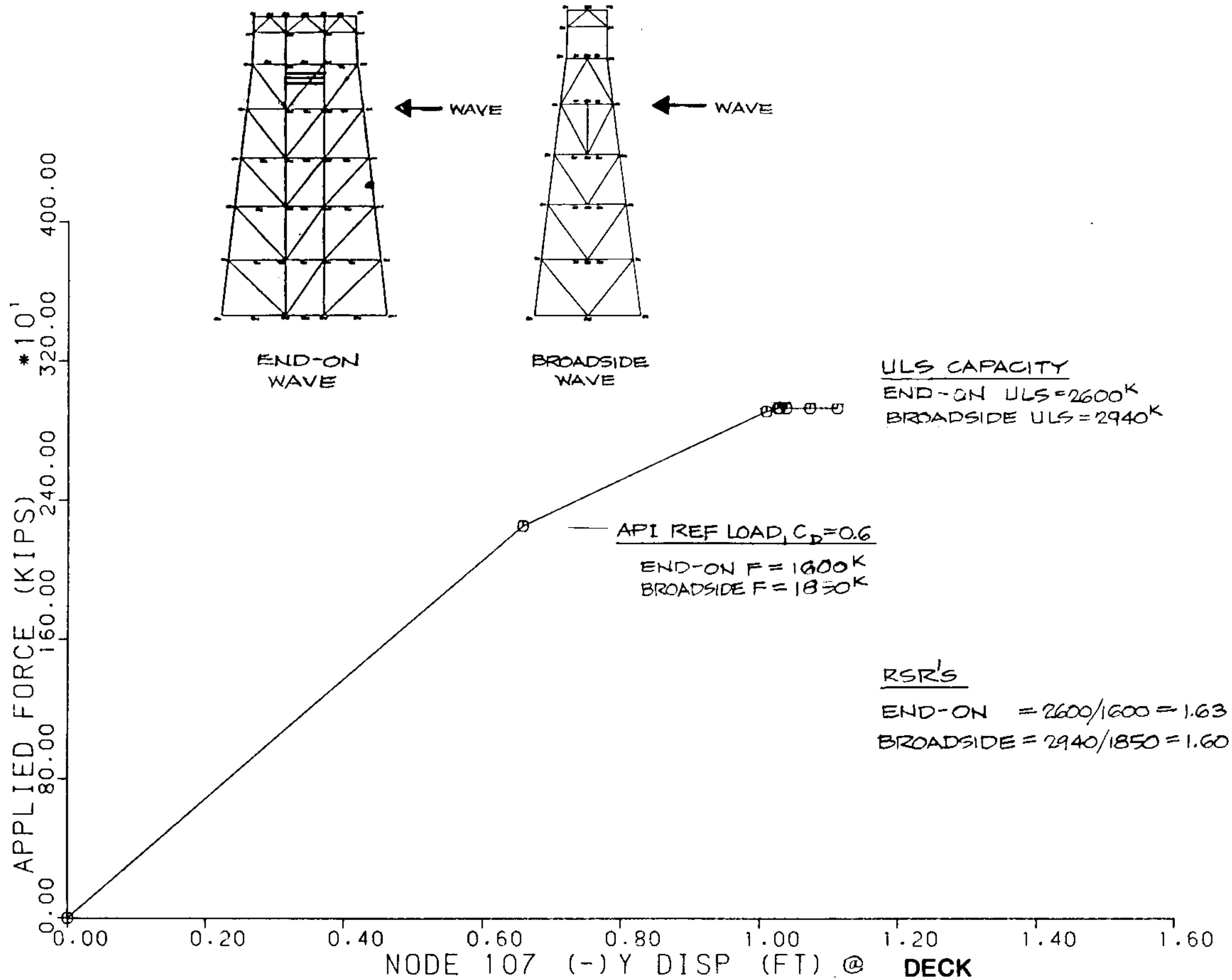


Figure 4-2 Platform "C" Static Push-Over Results and RSR

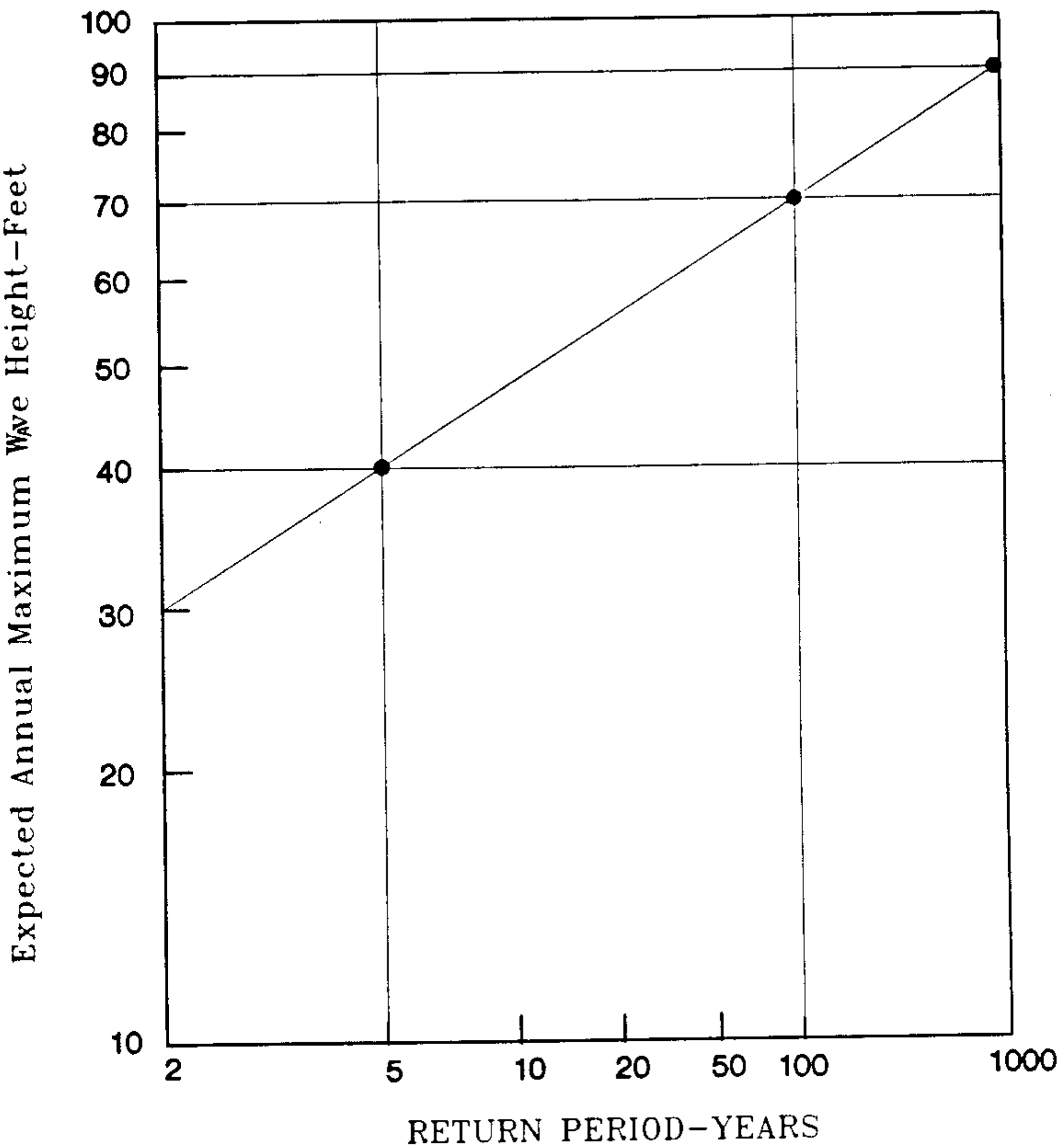


Figure 4-3 **Platform "C": Hurricane Expected Maximum Wave Heights and Return Periods**

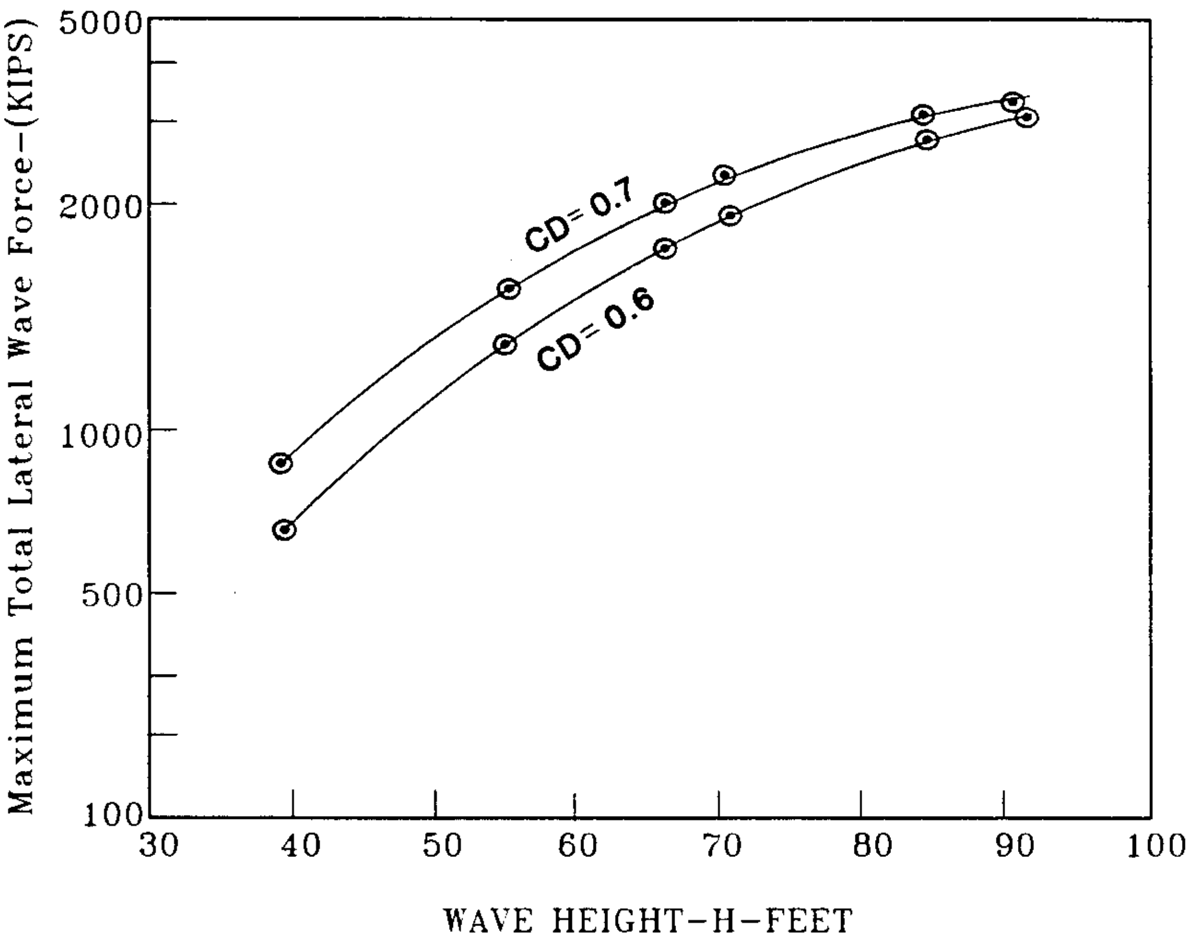


Figure 4-4 Relationship of Maximum Total Lateral Wave Force (End-On) to Wave Heights for Platform "C"

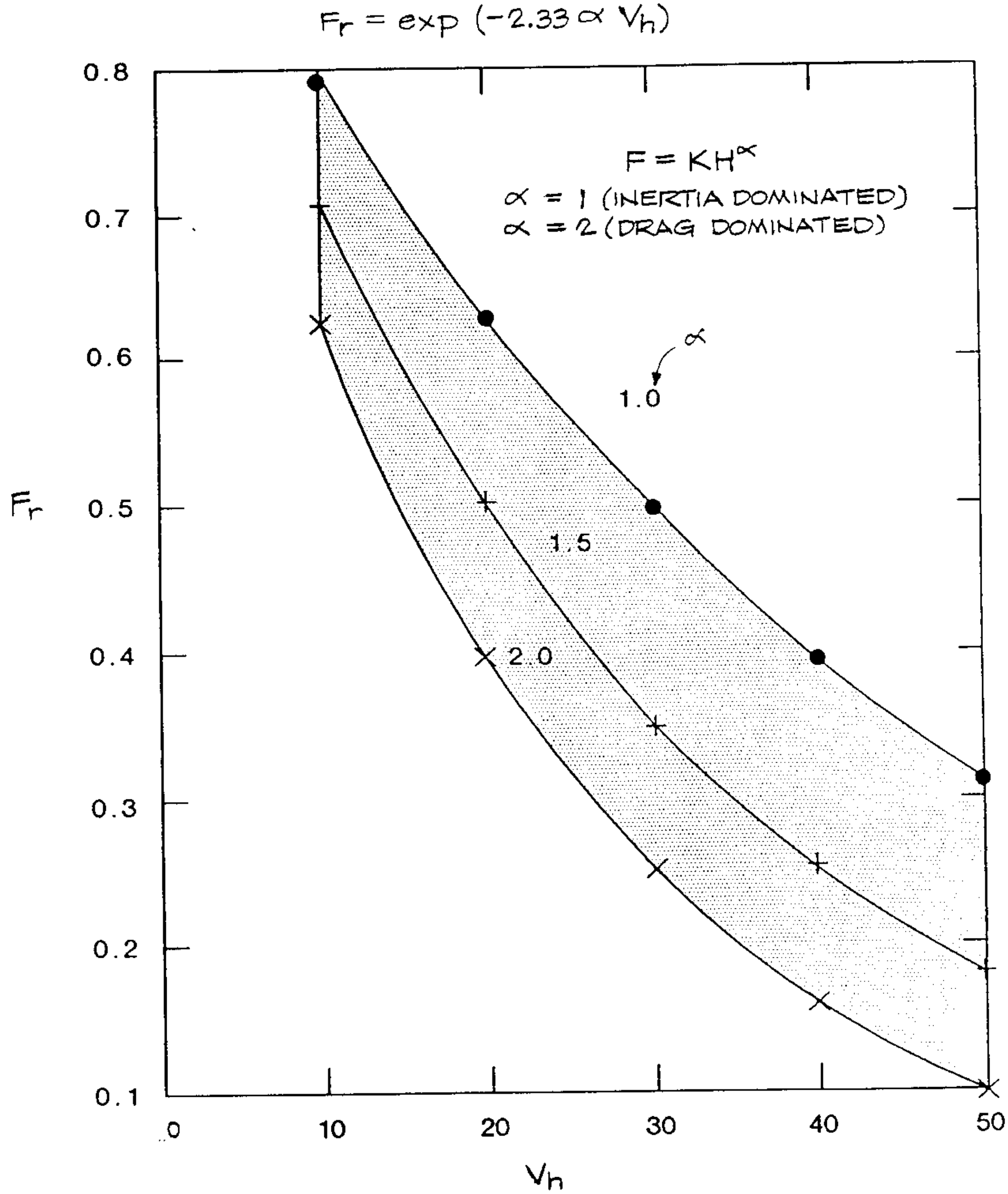
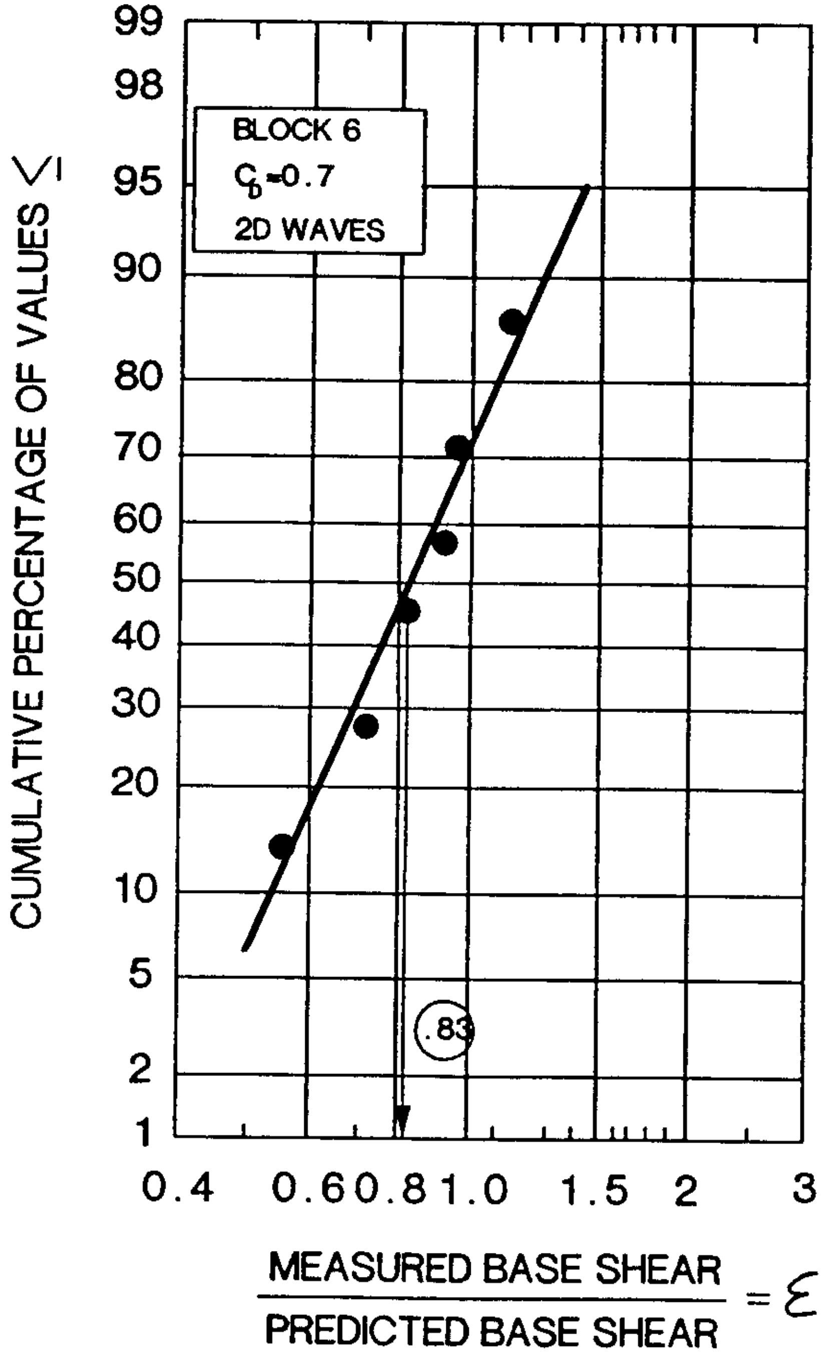


Figure 4-5 **Determination of the Force Ratio (FR) as a Function of the Expected Annual Maximum Wave Height Coefficient of Variation (V_h), and Wave Force Exponent (α)**



$\bar{\varepsilon} = \varepsilon_{50}$ (50TH PERCENTILE) $= 0.83 =$ "BIAS"

$V_\varepsilon = 0.39\,(\ln \varepsilon_{90} - \ln \varepsilon_{10}) = 0.29$

$V_{cf} = \exp(U_\varepsilon^2) - 1 = 0.30$

Figure 4-6 **Evaluation of Modeling Uncertainties Associated with Calculation of Wave Forces Given the Wave Heights and Periods**

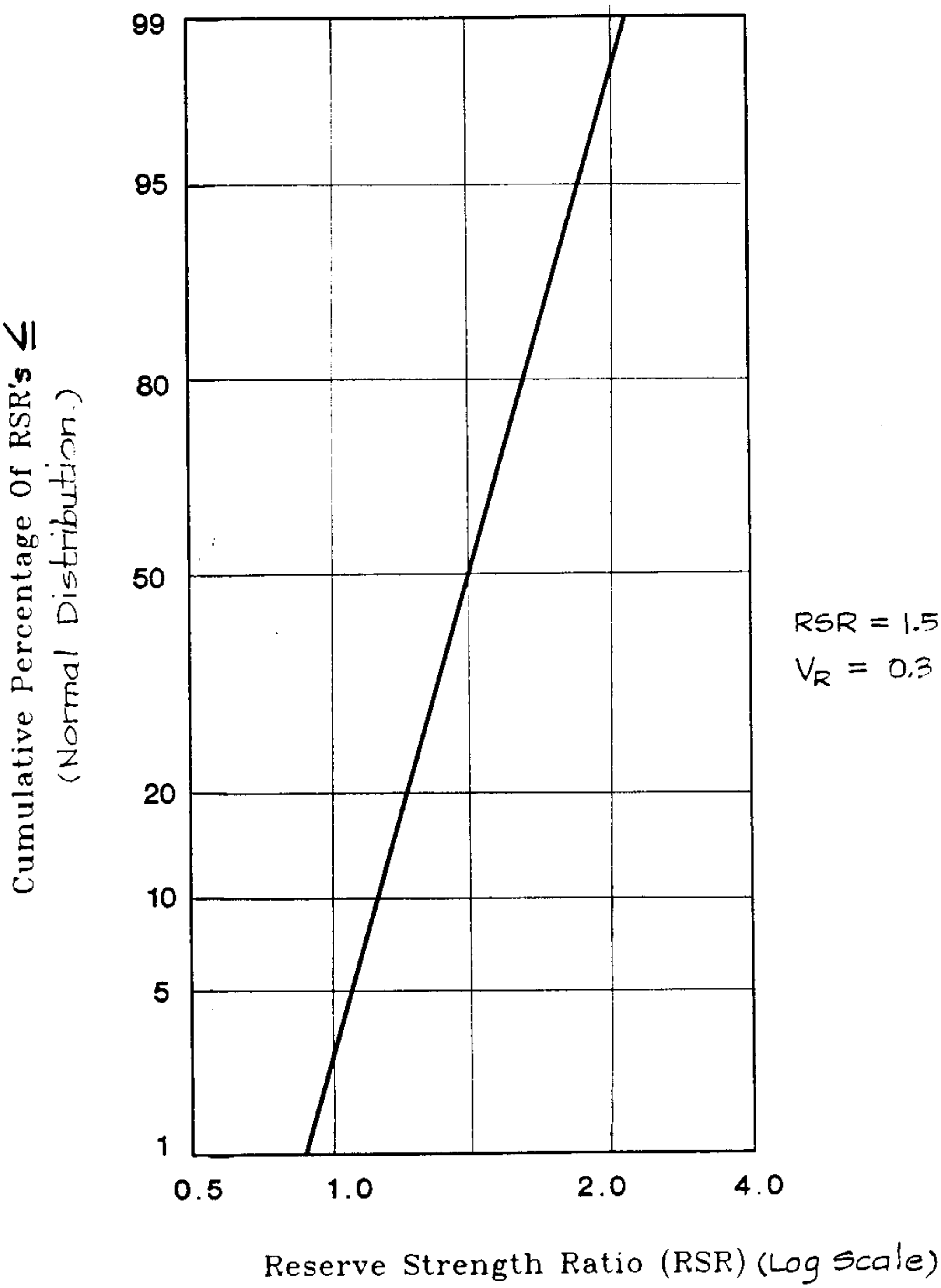


Figure 4-7 **Evaluation of Inherent and Modeling Uncertainties Associated With the Determination of the Platform Ultimate Limit State Capacity and RSR**

5.0 LIKELIHOOD OF LOSS OF SERVICEABILITY AND CONSEQUENCES

Three approaches to defining an acceptable or tolerable range of likelihood of loss of serviceability will be explored:

1. Historic (what has been accepted in the past).
2. Calibration (what is being accepted at the present).
3. Utility (what represents a highest utility option).

As discussed in the AIM-I and II reports [1,2], there are attractive and unattractive aspects of all three approaches. No single approach is best or perfect for all purposes. The three approaches should be viewed as being complementary. Insights developed by using the alternative approaches should be used to help make judgments, and to help facilitate communications concerning potential consequences and likelihoods.

in the range of 0.3 to 0.1 percent per year, and consequences to fall in the range of $1 to $10 millions (Category 1), and $10 millions to $50 millions (Category 2).

Given a likelihood of loss of serviceability in the range of 0.3 to 0.1 percent per year, the Safety Index (annual), $B = 2.76$ to 3.11 (equation 4). For purposes of this example, an "acceptable" historical data based $B = 2.76$ will be presumed in the subsequent analyses.

For the shallow water and moderate water depth platforms studied in AIM-II and III, the Force Ratios were in the range of $FR = 0.1$ to 0.2 (shallow and moderate water depth platforms) [2,18].

Note that for the AIM II and III platform locations, the COV's of expected annual maximum wave heights were in the range of $V_h = 0.38$ (AIM III Platform "C") to $V_h = 0.50$ (AIM II Platform "A"). Given a total maximum lateral force coefficient $\alpha = 0.2$, Force Ratios of $FR = 0.1$ ($V_h = 0.5$) to 0.17 ($V_h = 0.38$) would result. This is in good agreement with the range cited above determined directly from the calculated total maximum lateral forces.

In this evaluation, it will be contended that only natural or inherent variability uncertainties should be recognized when analyses are based on actuarial or historical data on platform failures. This is because the failure events do not involve engineering or modeling uncertainties. The platform is subjected to a specific maximum lateral force that exceeds a specific maximum lateral capacity. There are natural variabilities present in the events, but no calculation or modeling of uncertainties.

Based on capacity COV's in the range of V_r = 0.25 to 0.30 and expected annual maximum force COV's in the range of V_f = 0.75 to 1.0, resultant uncertainties in the range of U = 0.70 to 0.86 are indicated for the older, shallow and moderate water depth platforms.

Given an "acceptable" Safety Index of 2.76, the Force Ratio range FR = 0.1 to 0.2, and a loading-capacity uncertainty range of V = 0.70 to 0.86, RSR = 1.1 to 1.4 (equation 2).

Note that the high Force Ratio range (0.2) should be associated with the low uncertainty range (0.7) to keep appropriate force uncertainties in the two parts of equation 2 where U_f appears (FT and U).

These results indicate that given the Gulf of Mexico experience and the AIM-SS analytical framework, historically "acceptable" RSR's have been about 1.1 to 1.4. These lower range (marginal) RSR's have been associated with potential consequences that have been in the range of less than $1 million to $50 million (Figure 5-4).

Illustration of the definition of the historically based "marginal" RSR's and consequences could be based on the contention that the failure rates of the mid- to late-1960's would be marginal (Figure 5-1). The "marginal" analyses could be based on an annual failure rate of say 0.5 percent per year. This would equate to a Safety Index B = 2.58.

Again, using FR = 0.1 to 0.2 and U = 0.70 to 0.86, RSR = 0.92 to 1.2. Thus, the "marginal" range for RSR's for low consequence (Category 1) to low moderate consequence (Category 2a) platforms could be taken to be approximately 1.0.

Another illustration of the Historic Approach can be developed based on the information published by Whitman [19] (Figure 1-2). The lines that divide "accepted" and "marginally accepted" combinations of annual likelihood of loss of serviceability and consequences can be expressed analytically as follows [1]:

$$P_{fa} = 10^{-0.75 \log C + 1.75} \tag{13}$$

$$P_{fm} = 10^{-0.675 \log C + 0.975} \tag{14}$$

where P_{fa} is the "acceptable" annual likelihood of loss of serviceability, P_{fm} is the "marginal" annual likelihood loss of serviceability, and C is the total costs associated with the losses of serviceability (expressed in 1984 $millions).

The P_f's can be related to B's through equation 4, thus, relating "acceptable" and "marginal" Safety Indices to the consequences of loss of serviceability, C (Figure 5-5).

To relate the Safety Indices to the Reserve Strength Ratios, the following representative parameters will be used: U_f = 0.76, U_r = 0.25, U = 0.80, FR = 0.17. The results indicate a wide band separating the combinations of acceptable RSR's and consequences.

Note that the two historically based evaluations give a "marginal" range of RSR's and consequences that are in reasonable agreement (Figures 5-4 and 5-5).

5.2 Calibration Approach

Illustration of the calibration approach will be based on the three Gulf of Mexico platforms ("A", "B", "C") that have been studied during the AIM projects [2,18].

5.2.1 Platform "A"

Platform "A" (Figure 5-7) is a 25-year old unmanned structure that was severely damaged, repaired, and requalified for a 12-year remaining life with 2-year inspection cycles [2]. Depending on the AIM alternative, the platform has a ULS capacity between 950 kips (as-is, repaired condition) and 1440 kips (raised deck) (Figure 5-8). The platform was requalified for its present as-is repaired condition.

Based on a site and platform specific oceanographic and hydrodynamics study, the return periods associated with various magnitudes of maximum total lateral force (hurricane winds, waves, currents) were characterized (Figure 5-9).

During hurricane "Hilda" (1964, one year after the platform was installed), this structure experienced a maximum wave height estimated to be in the range of 50 to 55 feet [2]. This hurricane generated maximum total lateral forces on the platform estimated to be in the range of 1000 kips to 1400 kips. This is about the same range as the estimated initial intact (as-designed) ULS capacity. This storm was apparently responsible for a large amount of damage to the platform and its equipment (drilling rig was swept overboard).

Thus, platform "A's" performance has been consistent with the AIM demand and capacity analyses.

In its present as-is condition (without deck raising), platform "A" has an RSR = 950 kips / 1532 kips = 0.62 (based on API minimum wave force guidelines and considering waves in the decks).

Platform "A's" ULS capacity (as-is) would be exceed by a force event having a return period in the range of 33 to 50 years. This equates to a likelihood of loss of serviceability of 2 to 3 percent per year (equation 5).

Given platform "A's" loss of serviceability, the operator's production re-development analysis indicated that the structure would not be replaced. The platform AIM program, salvage, clean-up, and abandonment costs were estimated to be in the range of $3.70 to $19.2 millions [2].

5.2.2 Platform "B"

Platform "B (Figure 5-10) is a 30-year old unmanned platform, that was damaged, repaired, non-functional elements in the wave zone removed (boat landings), marine growth removed, and requalified for a 5-year remaining life with 2-year inspection cycles [2]. Under these conditions, the platform had a ULS capacity of approximately 1000 kips (end-on wave approach, Figure 5-11).

Based on a site and platform specific oceanographic and hydrodynamic study, the platform maximum total lateral forces and associated average annual return periods were characterized (Figure 5-12). The reference force (API 100 year minimum) was 1000 kips.

Three years after platform "B" was installed, the center of hurricane "Carla" (1961) passed within a few miles of the platform location. This storm generated maximum wave heights at the platform estimated to be about 40 feet [2]. Given these wave conditions, the total maximum lateral force developed on the platform is estimated to have been in the range of 600 to 700 kips. The intact (undamaged) initial ULS capacity of the platform is estimated to have been about 1000 kips.

In 1985, hurricane "Alicia" developed maximum wave heights estimated to have been in the range of 45 to 47 feet [2]. Given these wave conditions, the total maximum lateral force developed on the platform is estimated to have been in the range of 800 to 900 kips. At the time of this storm, the platform (damaged braces) is estimated to have had a ULS capacity of about 1000 kips (damage had negligible influence on capacity).

Thus, platform "B" has performed as expected during past intense hurricane loading events.

Platform "B's" RSR = 1.0. Platform "B's" ULS capacity would be exceeded by a force event having a return period of 100 years. This equates to a likelihood of loss of serviceability of 1.0 percent per year.

Given platform "B's" loss of serviceability, the operator's production re-development analysis indicates that the structure would not be replaced. The platform AIM program, salvage, clean-up, and abandonment costs were estimated to be in the range of $2.35 to $10.85 millions [2].

5.2.3 Platform "C"

Platform "C" (Figure 5-13) is a 19 year old, standard 8-leg drilling and production structure that has been well maintained. Operating personnel on this platform are evacuated in advance of hurricanes. The platform has a ten-year remaining life. The platform operator proposes to requalify this platform for its remaining life in its present condition using annual "Level I" surveys (visual above water, cp verification), and 5-year interval "Level III" surveys (underwater visual, NDT of high consequence-high likelihood elements) [18].

In its present condition, platform "C" has an ULS capacity in the range of 2600 kips (end-on) to 2940 kips (broadside) (Figure 8).

Based on site and platform specific oceanographic and hydrodynamic studies, the platform's expected maximum total lateral forces and return periods were characterized (Figure 4-1). The API based reference force fell in the range of 1600 kips (end-on wave approach) and 1850 kips (broadside wave approach).

Platform "C's" RSR is approximately 1.6 (Figure 4-2). Platform "C's" ULS capacity would be exceeded by force events having a return period of about 200 to 400 years. This equates to a likelihood of loss of serviceability of 0.25 to 0.50 percent per year.

Given platform "C's" loss of serviceability, the operator's production re-development analysis indicates that the structure would not be replaced. The platform AIM program, salvage, clean-up, and abandonment costs are estimated to be in the range of $19.5 to $35.5 millions (based on cost data in reference [2]). Given installation of wireline retrievable-flapper type surface controlled subsurface safety valves (SSSV's) in the producing wells, the platform AIM program, salvage, clean-up, and abandonment costs are estimated to be in the range of $21.3 to $26.7 millions. (Note the increase in lower range cost is due to installation costs of SSSV's.)

5.2.4 Calibration Summary

The three Gulf of Mexico platform AIM program calibration examples can be used to define the combinations of RSR's and consequences that are being accepted at the present time (Figure 5-14). The data have been plotted as the estimated range of RSR (best estimate ±5 percent) and potential consequences (full range of cited values).

Note that The calibration results are in reasonable agreement with those from the historic data evaluations discussed earlier (Figures 5-5 and 5-6).

5.3 Utility Approach

The fundamental premise of this approach is that the "best" AIM platform requalification alternative is one that produces the lowest total expected costs. Stated in another way, this approach attempts to define the AIM program that will maximize the utility (or measure of worth) associated with this aspect of a platform's operations.

Note that the identification of the best platform requalification program does not assure the commercial viability of a platform operation. The utility approach attempts to do all that is reasonable in the context of AIM operations to assure the continued viability of a platform operation (minimize costs).

The utility approach that will be used in this study is a basic cost-benefit evaluation that is based on the premise that the best program alternative is the one that produces the lowest total expected cost. The expected total cost is the sum of expected initial costs and expected future costs (Figure 5-15):

$$E(C) = E(I) + E(F) \tag{15}$$

Initial costs include all costs to modify the platform for the alternative, plus all costs associated with future platform maintenance designated by the alternative. Initial costs include structure repair and modifications, operations (e.g. reducing onboard storage, adding down-hole well safety shut-in equipment), engineering, and inspections (current, planned).

Future costs, F, include all costs associated with loss of serviceability (or failure) of the platform including [16]:

A. Costs Associated with Net Revenues (expected losses due to deferred production, lost production costs);

B. Restoration Costs (expected salvage costs, costs of plugging wells, pollution abatement and cleanup, costs associated with injuries, and other negative impacts);

C. Replacement Costs (platform replacement, equipment replacement, costs of redrilling wells).

Note that replacement costs would only be included in the evaluation of potential future costs if the income from the platform operation would justify such costs. For the older platforms in which recoverable reserves are very low, it is very likely that the platform would not be replaced.

The expected costs are computed as the product of the total cost and the likelihood of experiencing that cost. In the case of the expected future cost:

$$E(F) = (F)(Pf)(PVF) \tag{16}$$

Where F is the total future cost (given a platform loss of serviceability), Pf is the likelihood of experiencing the loss of serviceability (annual chance of failure), and PVF is a present value function. The PVF for a platform AIM cycle period, L, and net (true - inflation) investment rate r, can be represented as a continuous discount function:

$$PVF = \frac{1-(1+r)^{-L}}{r} \tag{17}$$

For long L's and replacements in the event of loss of serviceability: PVF = 1/r.

For short L's and low net investment rates, PVF = L.

Note for the cases of non-replacement of structures whose serviceability has been lost, and deferred revenues considered, more complex PVF's will need to be considered [16].

Also, it should be noted that the exposure period for the platform in these analyses has been defined as the length (in years) of the present AIM cycle, L. It is not defined as the total expected life of the structure. This is because of the presumed continuous updating and upgrading implied in requalification programs over the life of the platform. It is in this way that the length of the AIM cycle enters the decision concerning the optimum or desirable AIM program for a platform at a given point in time. At this stage, no attempt is made to project the future outcomes or developments of AIM cycles.

More complex evaluations could recognize potential decreases in the platform capacity with time [1,17], and project results from strengthening programs with time. The development of Inspection, Maintenance, and Repair (IMR) programs to recognize such effects and to integrate those effects into RSR evaluations is a topic for future AIM project efforts.

One of the concerns with the expected value utility analysis is that the multiplication of low likelihoods of loss of serviceability (P_f) and costs of potential future losses (F) can give unreasonably low weighting to the possible implications of losses of platform serviceability. A second related concern is that the quantitative assessments of the likelihoods of loss of platform serviceability are not dependable enough to base decisions upon.

The expected value of an AIM decision alternative is the average monetary result per decision that would be realized if the decision maker accepted the alternative over a series of identical repeated trials. The expected value concept is a philosophy for consistent decision making, which, if practiced consistently can bring the sum total of the utilities of the decisions to the highest possible level. The expected value is not an absolute measure of a monetary outcome. It is incorrect to believe that the expected value is the most probable result of selecting an alternative.

Relative to the second concern with the quantitative evaluations of likelihoods of loss of serviceability, they must be reasonable and realistic. It should be remembered that these quantitative evaluations are being used in a comparative sense, one AIM alternative versus another. Consistency in the methods used to develop, interpret, and apply the likelihoods is a primary requirement.

The last point with these concerns is that if the decision makers believe that the consequences of loss of serviceability are not being given their proper weighting, then an alternative decision making process known as "Utility Theory" [20,21,22] can be applied to recognize the risk-consequence characteristics of the decision makers.

Given that the costs associated with the AIM alternatives that determine the platform reliability are related linearly to the log of the probability of loss of serviceability (Figure 5-15), the Safety Index (annual) which produces the lowest combination of expected initial costs and potential future losses resulting from platform loss of serviceability, B_0, can be determined as [11,16]:

$$B_o = \left[-\ln \frac{0.915}{(PVF)(CR)} \right]^{0.625} \qquad (18)$$

Where CR is the cost ratio: the ratio of the expected cost of the platform loss of serviceability to the cost needed to decrease the annual likelihood of the platform loss of serviceability by a factor of 10. This equation is derived in Appendix B.

Given the best or optimum (from an expected cost standpoint) Safety Index, B_0, the associated RSR can be determined from equation (2).

For example, platform "A's" likelihood of loss of serviceability could be decreased by a factor of 10 by raising the decks. For a projected loss of serviceability cost of $3.3 million (non-replacement) [2], and a cost of raising the decks of $1 million, CR = 3.3.

Assuming PVF = 2, equation (18) would indicate a best AIM alternative Safety Index, B_0 = 1.53. Based on a Force Ratio, FR = 0.13, and an Uncertainty measure U = 0.8, the Safety Index of 1.53 would equate to a best alternative AIM program RSR = 0.44. The platform (as is, without raised decks) had an RSR = 0.62, thus, the proposed AIM program would develop an RSR that would exceed that indicated to be the best based on an expected cost evaluation.

The product of the Cost Ratio, CR, and the Present Value Function, PVF (= L for short AIM cycles), can be interpreted as a measure of Consequences, C, associated with a platform's loss of serviceability.

Equations (18) and (2) can be used to define the RSR's associated with the Consequences measure for different values of Force Ratios and Uncertainty measures (Figure 5-16).

The data for the three AIM platforms discussed earlier in this section have been plotted in Figure 5-16.

For cases in the Gulf of Mexico (e. g., $F_r = 0.13$, $U = 0.8$, and $FR = 0.2$, $U = 0.7$) with consequences that could be placed in the low to lower moderate ranges ($C = 1$ to 20), RSR's in the range of 0.3 to 1.0 are indicated (Figure 5-16).

The foregoing minimum expected costs rationale could be used to assess placement of the "acceptable" dividing line between fit-for-purpose and not-fit-for purpose conditions (Figure 3-1). Assessment of the placement of the "marginal" line will require an additional development in this framework.

In this context, a criterion could be developed that focuses on the very broad valley of minimum total expected costs (Figure 5-15), and the point at which the expected costs of loss of serviceability rapidly escalate (to the right in Figure 5-15 toward increasing likelihoods of loss of serviceability).

If assumed that the criterion to define the marginal likelihoods of loss of serviceability (Figure 5-15) were the point on the total cost of loss of serviceability curve where a slope equal to that of the initial AIM cost curve was developed, then the marginal safety index, B_m, could be defined as:

$$B_m = \left[-\ln \frac{1.83}{(PVF)(CR)} \right]^{0.625} \tag{19}$$

The "acceptable" and "marginal" lines have been drawn in Figure 5-17 based on equations (18) and (19), respectively, for a Force Ratio, FR = 0.2, and Uncertainty Measure, U = 0.7. In addition, a second "marginal" line has been shown based on the criterion of the total cost of loss of serviceability curve reaching a slope equal to twice that of the initial cost curve.

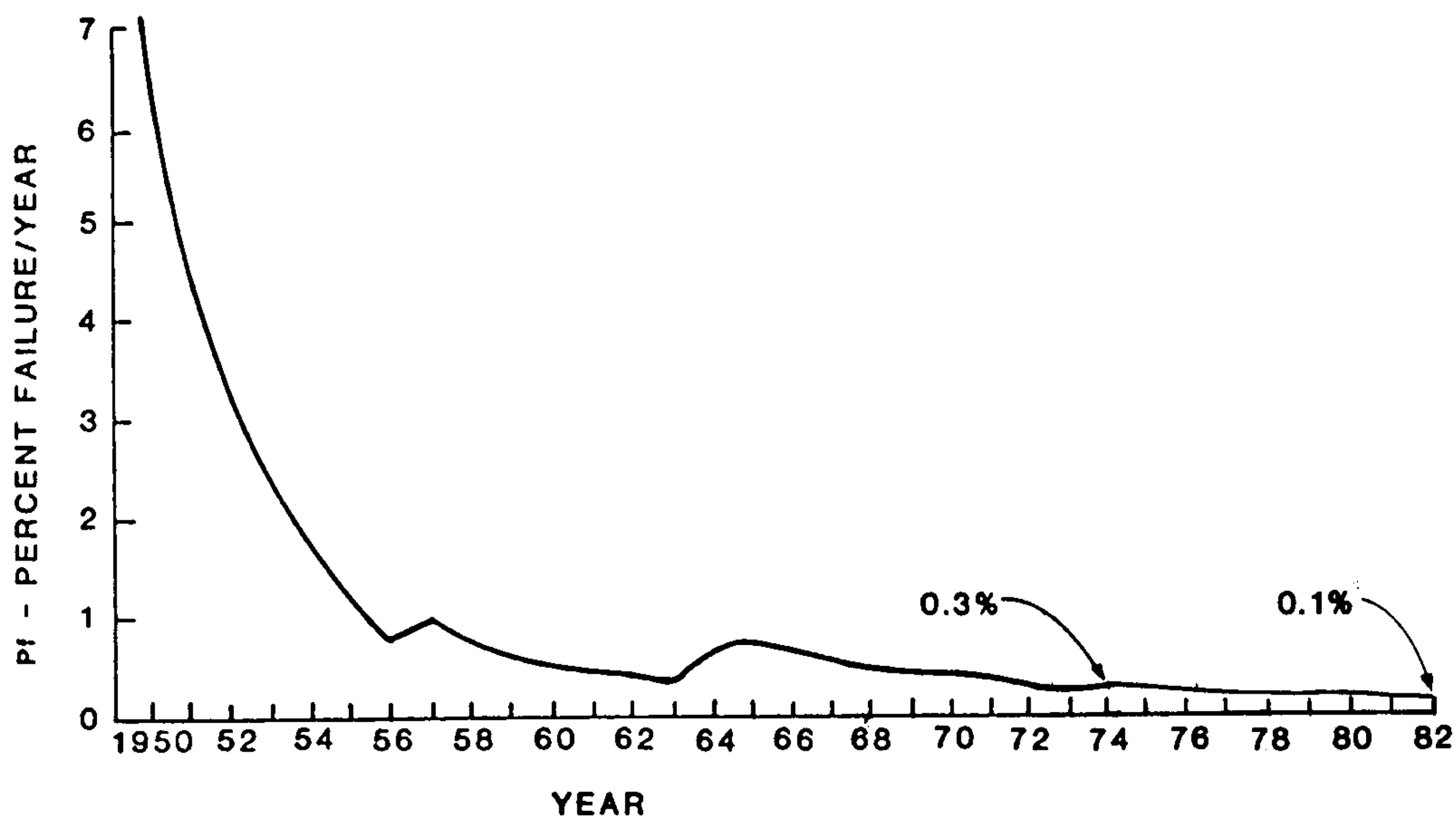
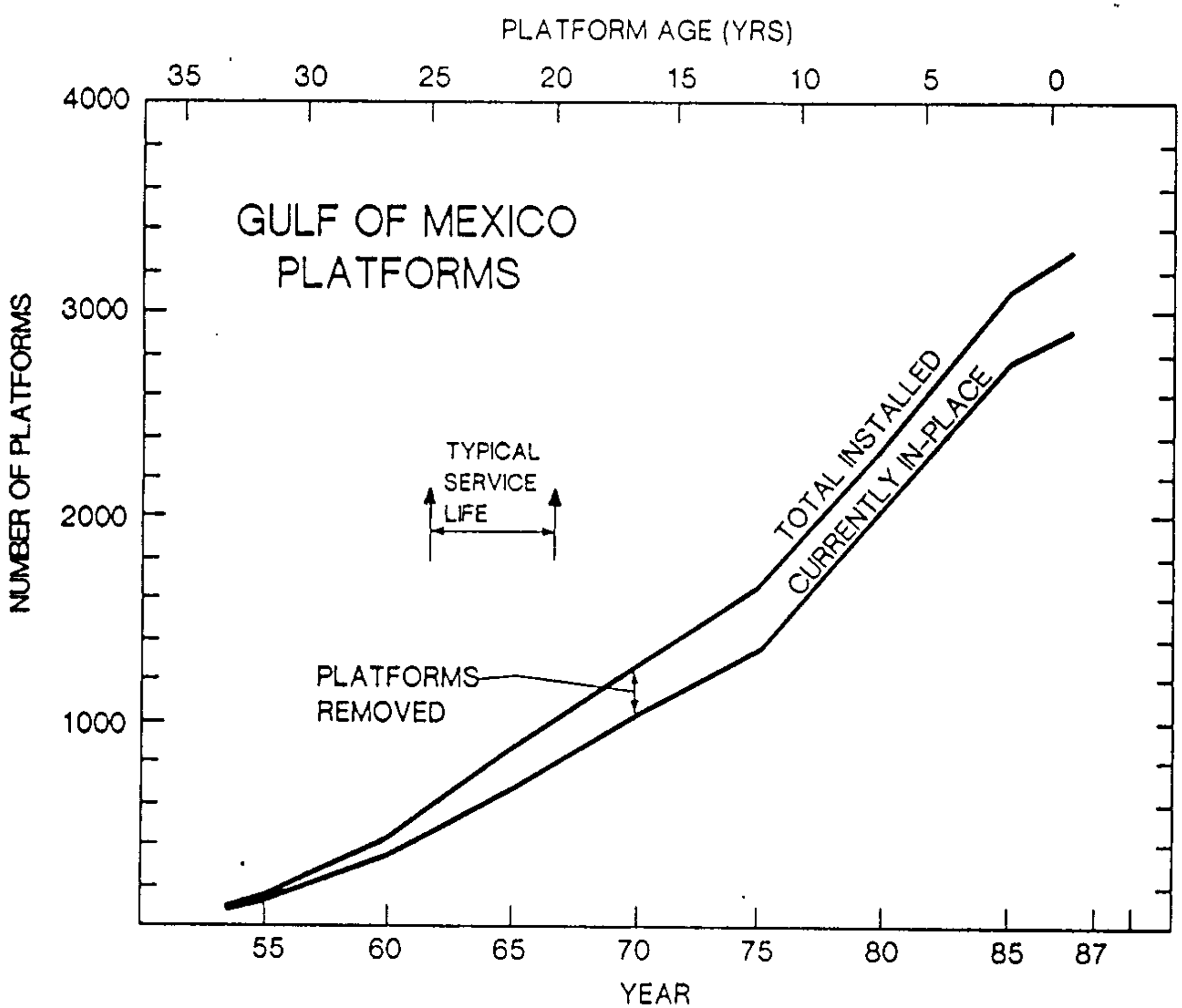


Figure 5-1 **Loss of Serviceability Rates Associated with Major Drilling and Production Platforms Due to Hurricanes in the Northeast Gulf ` Mexico 1950-1982**



SOURCE: OFFSHORE DATA SERVICES, 1987

Figure 5-2 **Numbers of Major Drilling and Production Platforms Installed and Removed in the Gulf of Mexico 1950-1987**

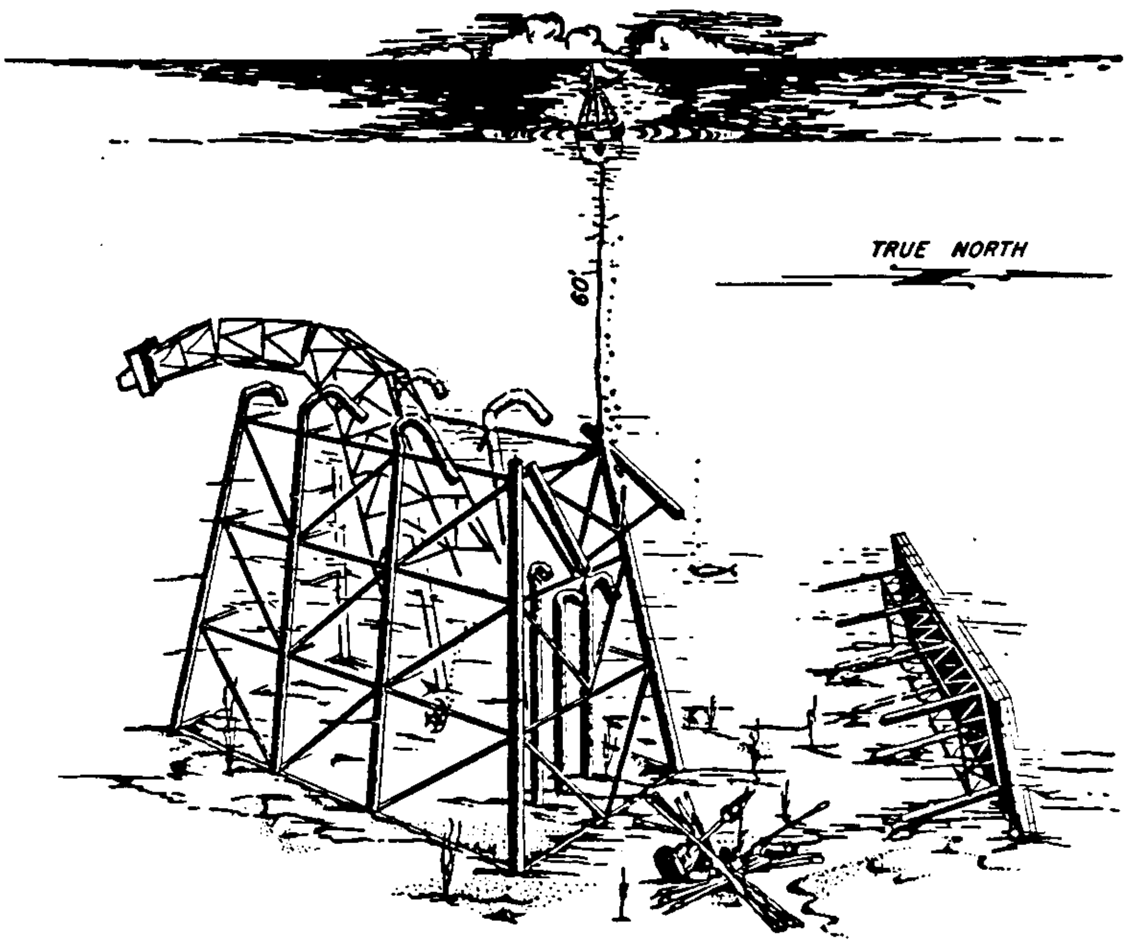


Figure 5-3 Platform Loss of Serviceability Event During Hurricane "Hilda" (1964)

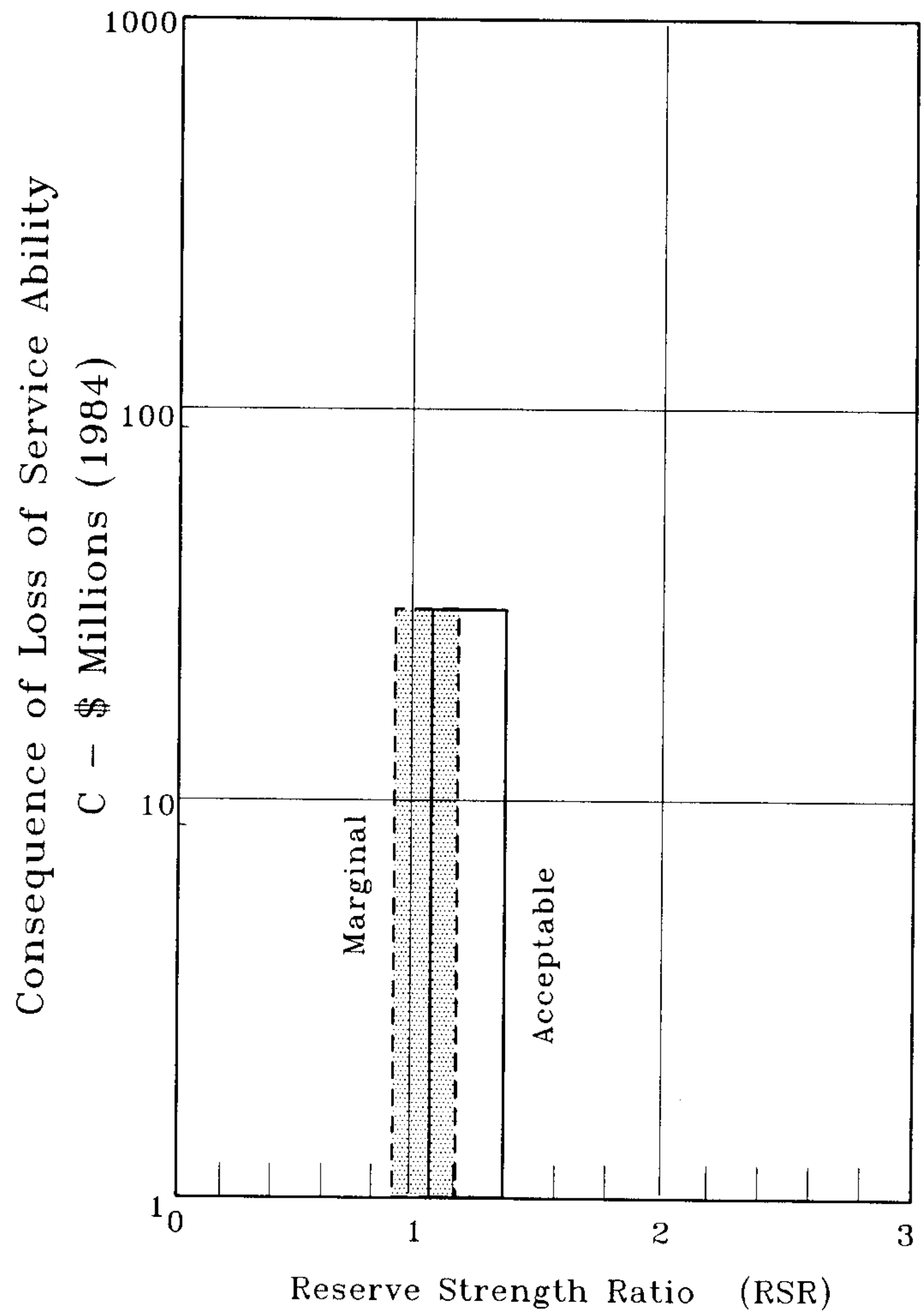


Figure 5-4 **Historic Data Based Measure of Consequences of Loss of Serviceability and RSR's of Major Drilling and Production Platforms in the Northeast Gulf of Mexico**

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FIG17

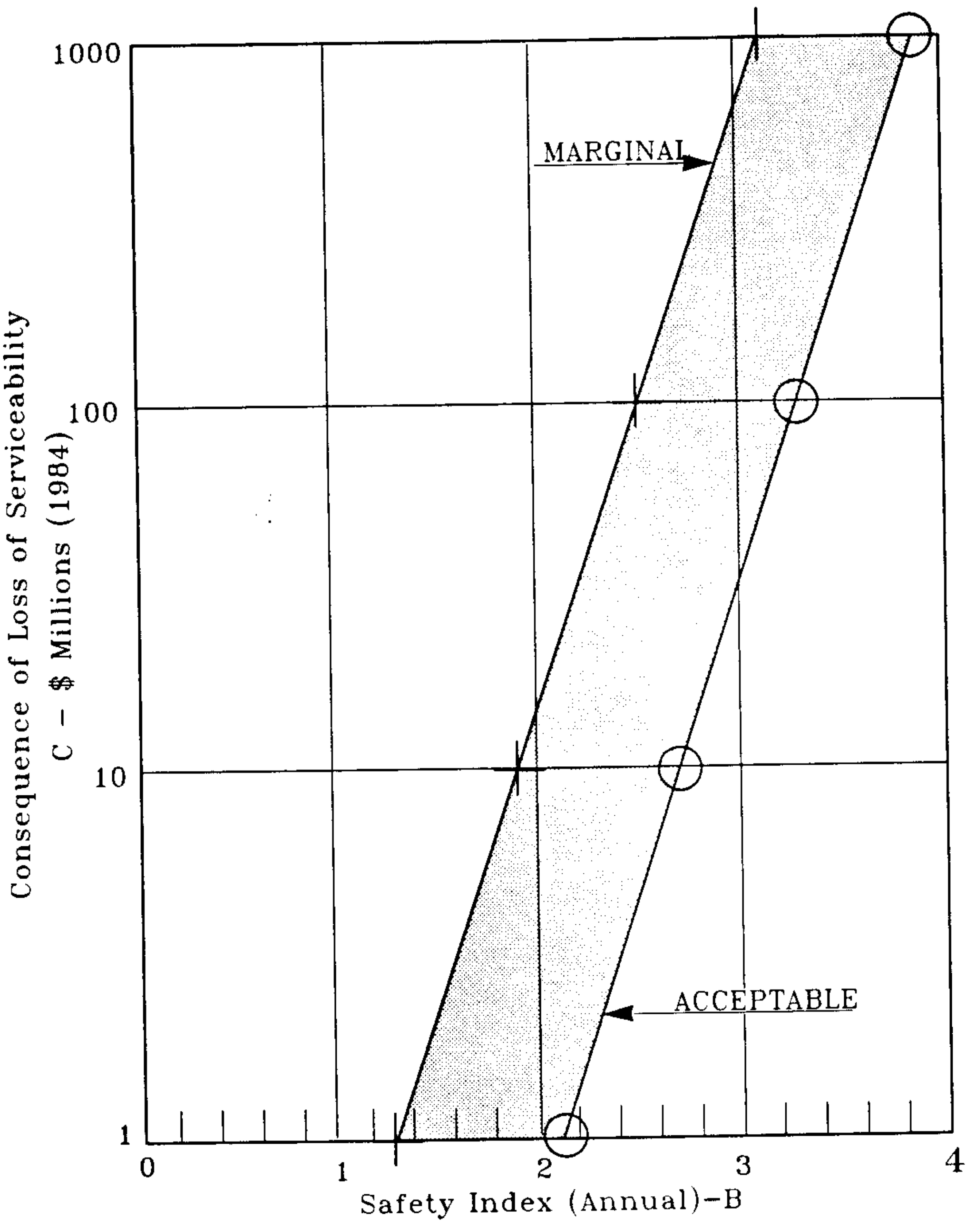

Figure 5-5 **Historic Data Based Relationship of Consequences of Loss of Serviceability and RSR's Based on Engineered Structures Performance (Figure 1-2)**

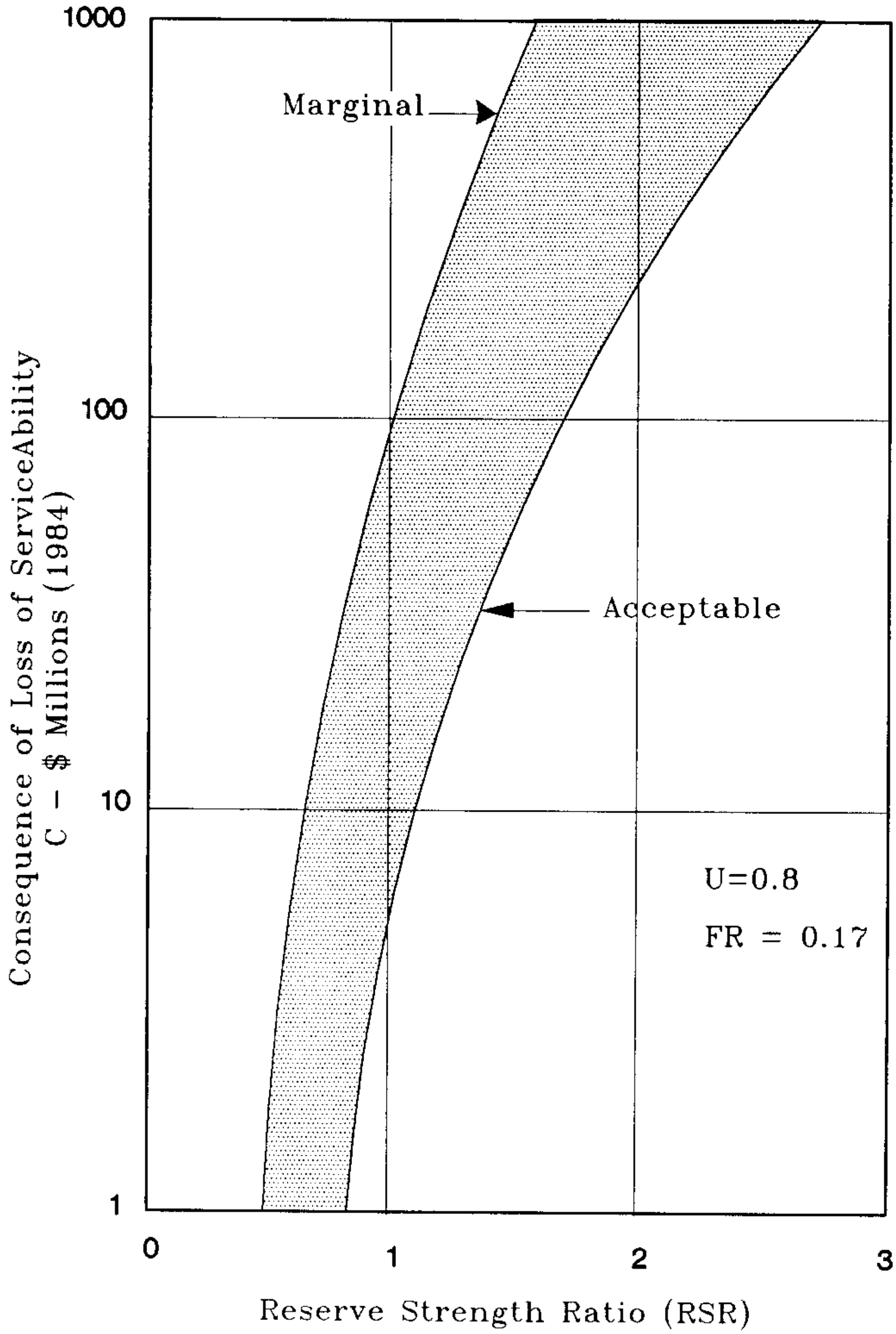

Figure 5-6 **Relationship of Consequences of Loss of Serviceability to RSR for Example Resultant Uncertainty Measure (U = 0.8) and Force Ratio (FR = 0.17)**

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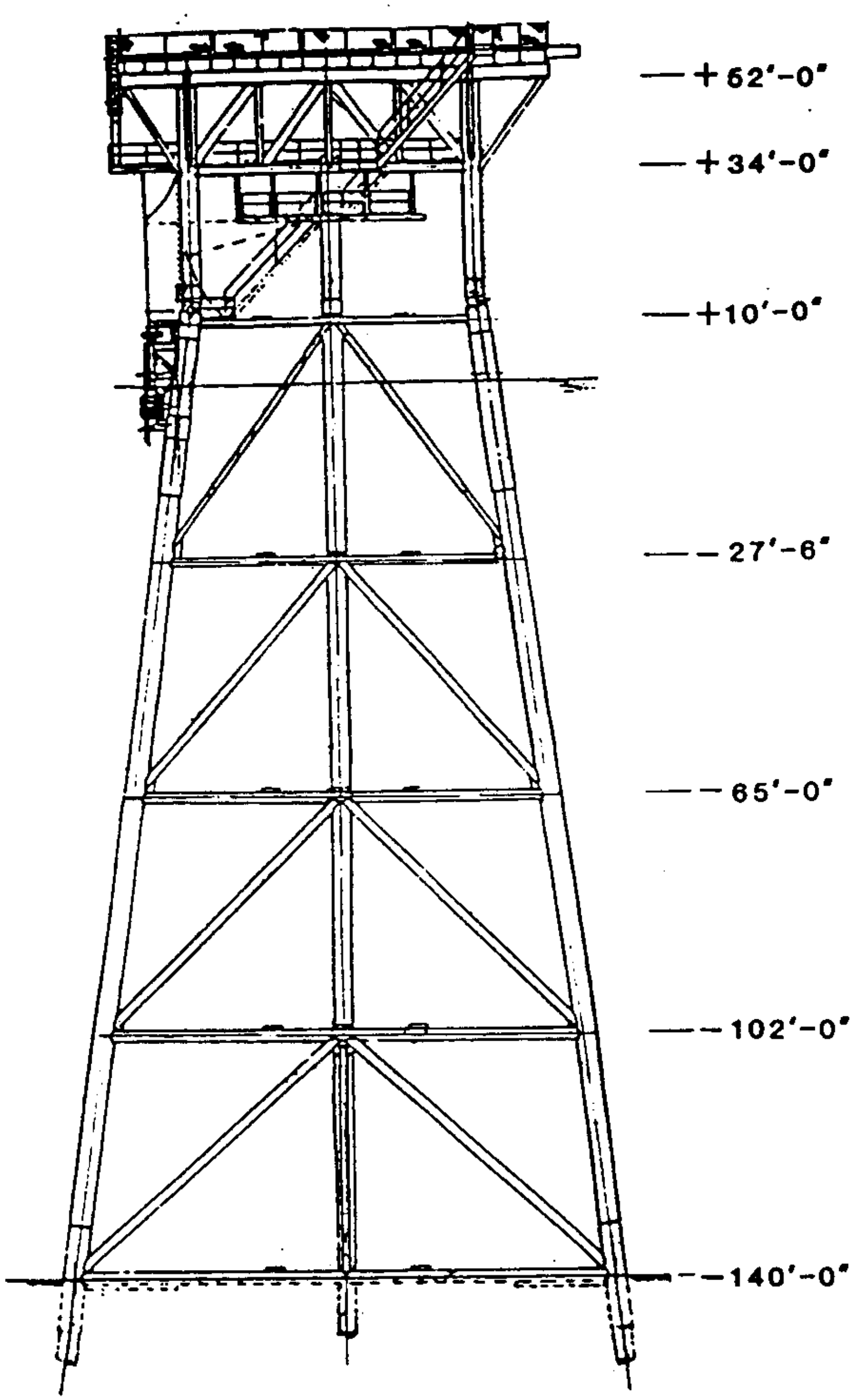
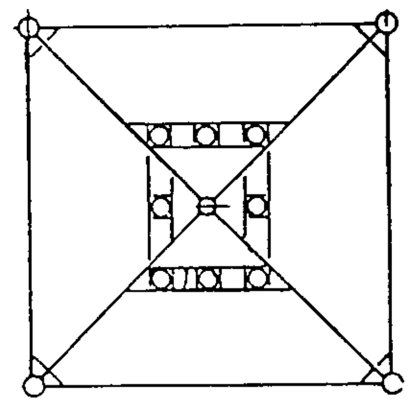
/AIM/CHRTS/
FIG-8.DRW



PLATFORM "A"



PLAN

Figure 5-7 Calibration Platform "A"

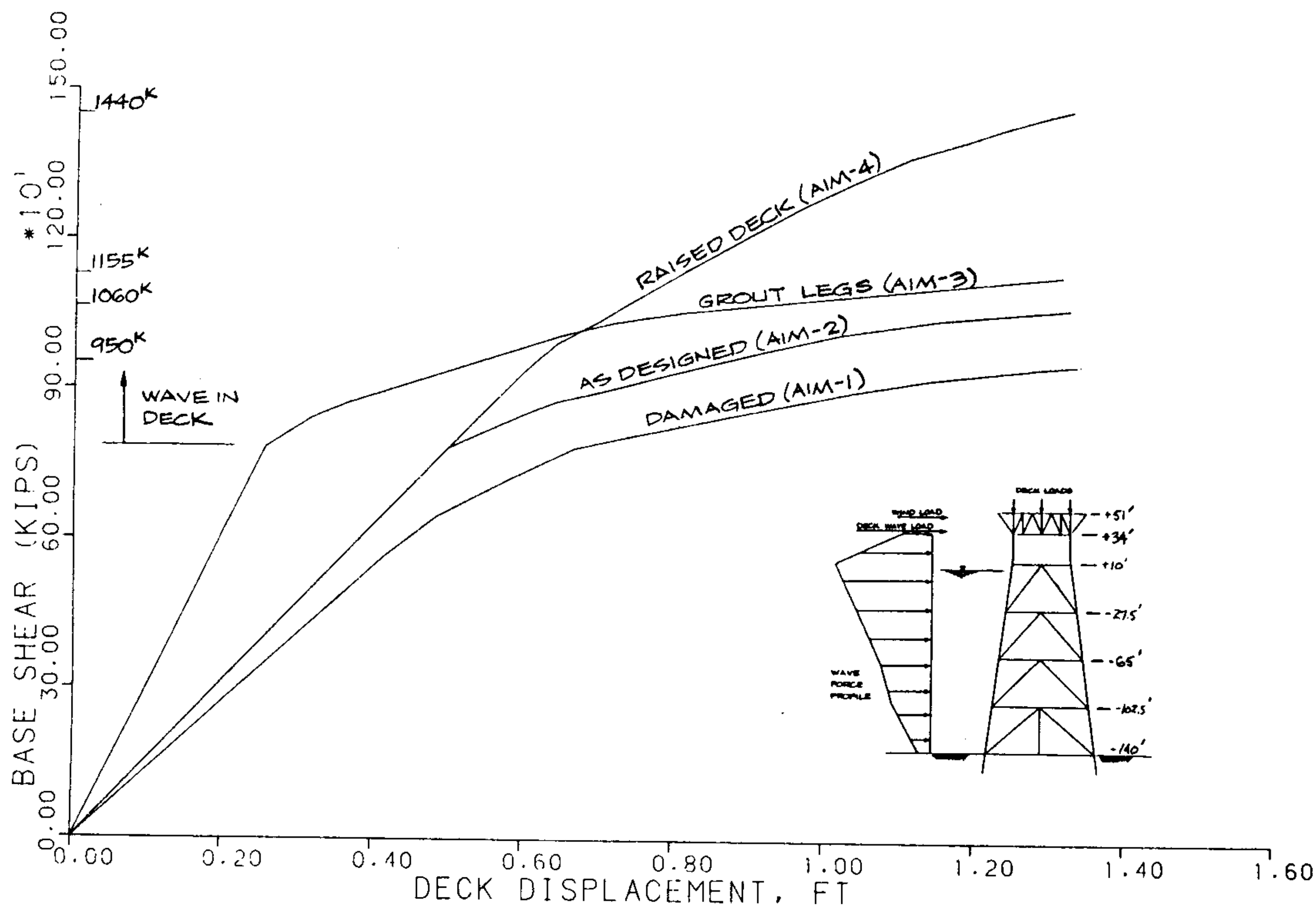


Figure 5-8 Platform "A" RSR Based on Static Push-Over Analysis

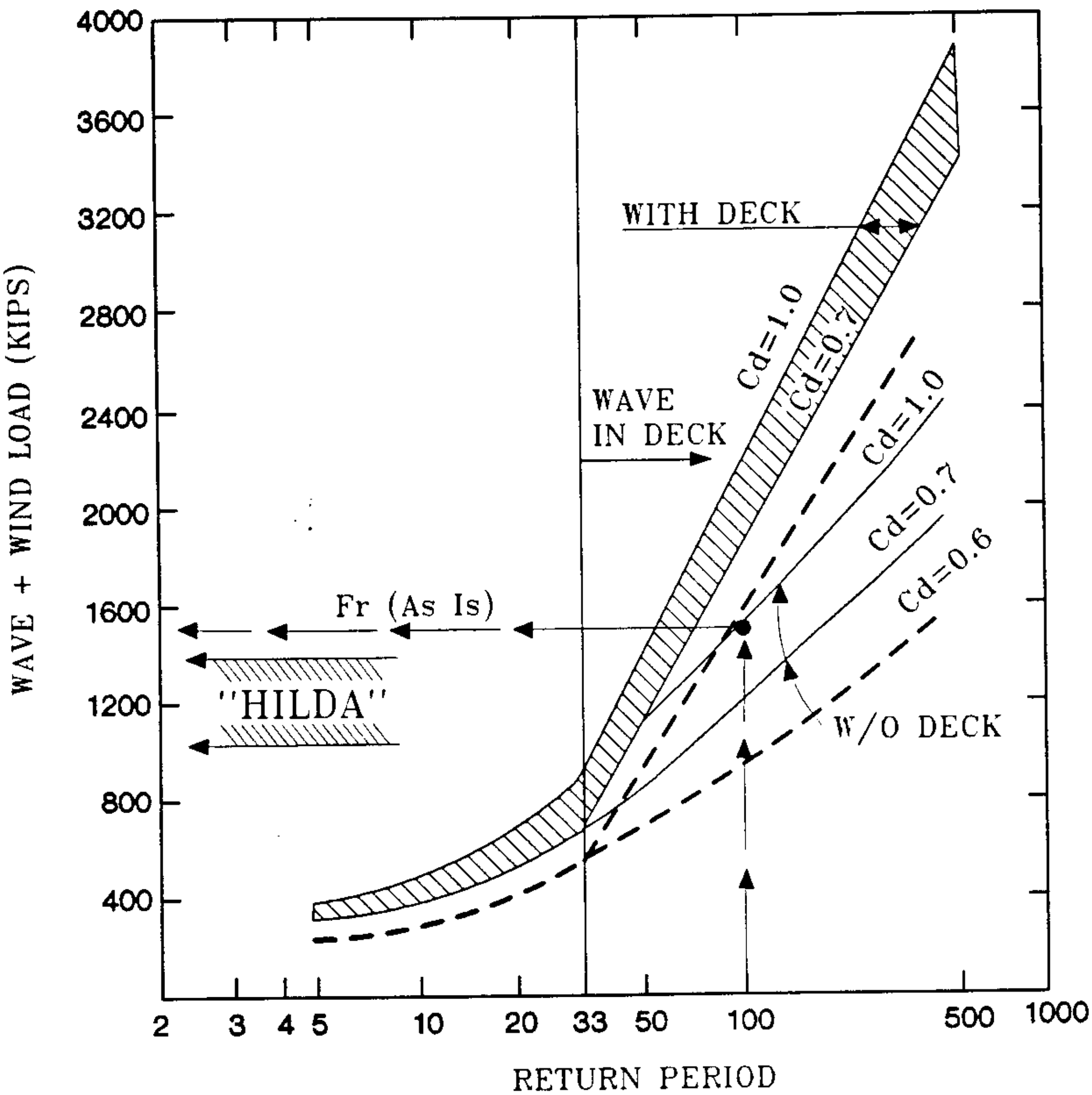


Figure 5-9 **Platform "A" Hurricane Expected Maximum Total Lateral Forces (Wind, Wave, Current) and Return Periods**

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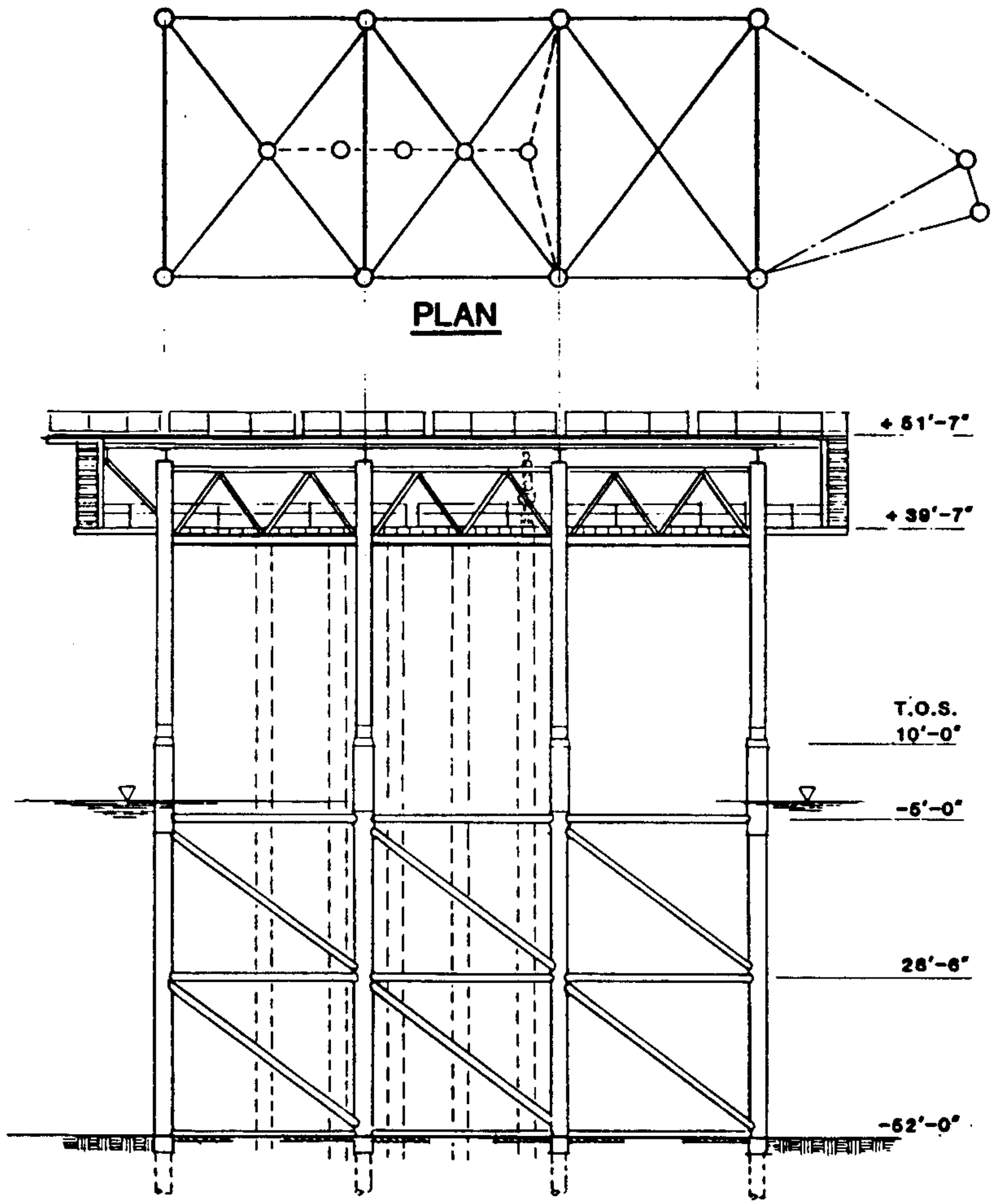


PLATFORM "B"

Figure 5-10 Calibration Platform "B"

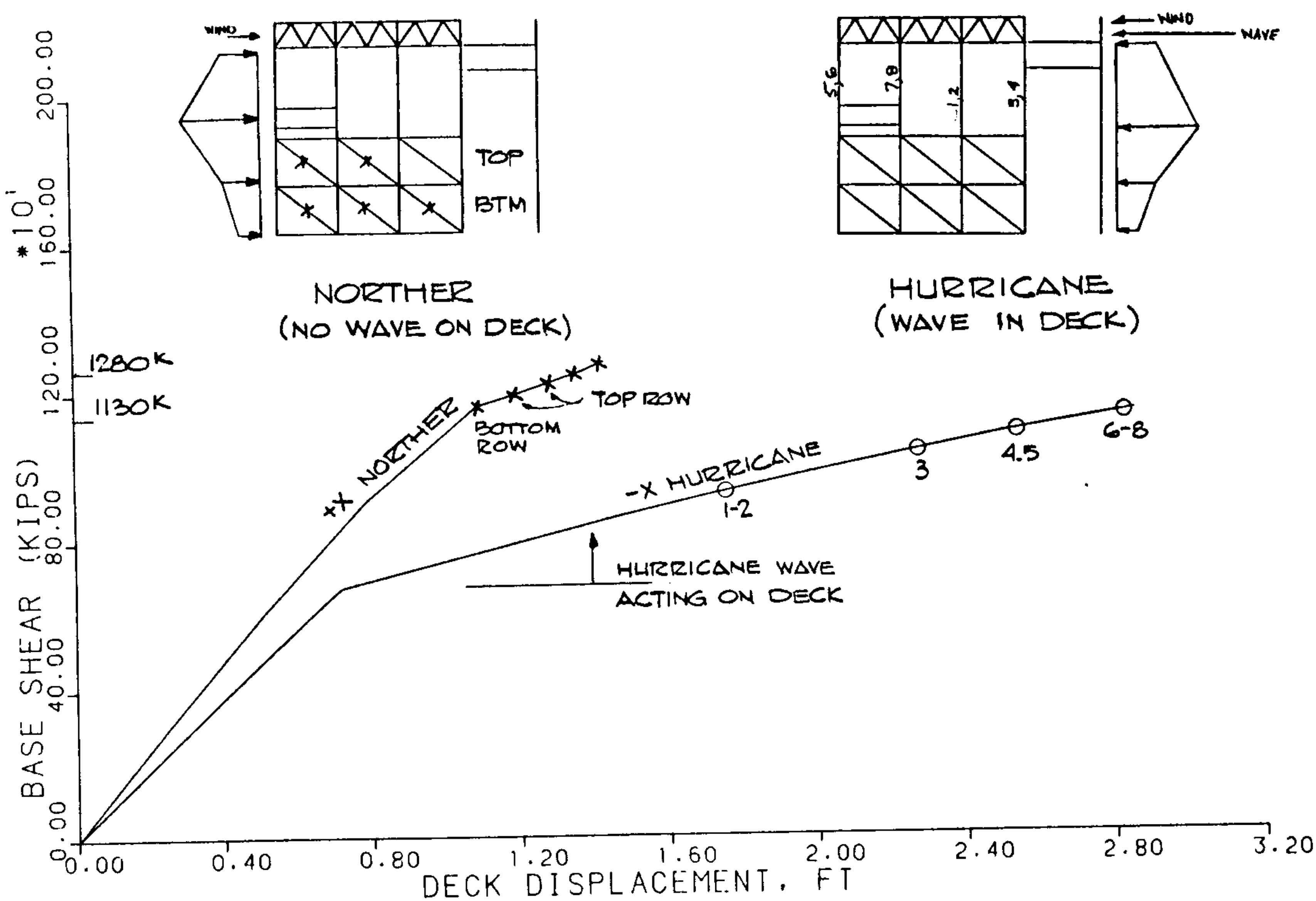


Figure 5-11 Platform "B" RSR Based on Static Push-Over Analysis

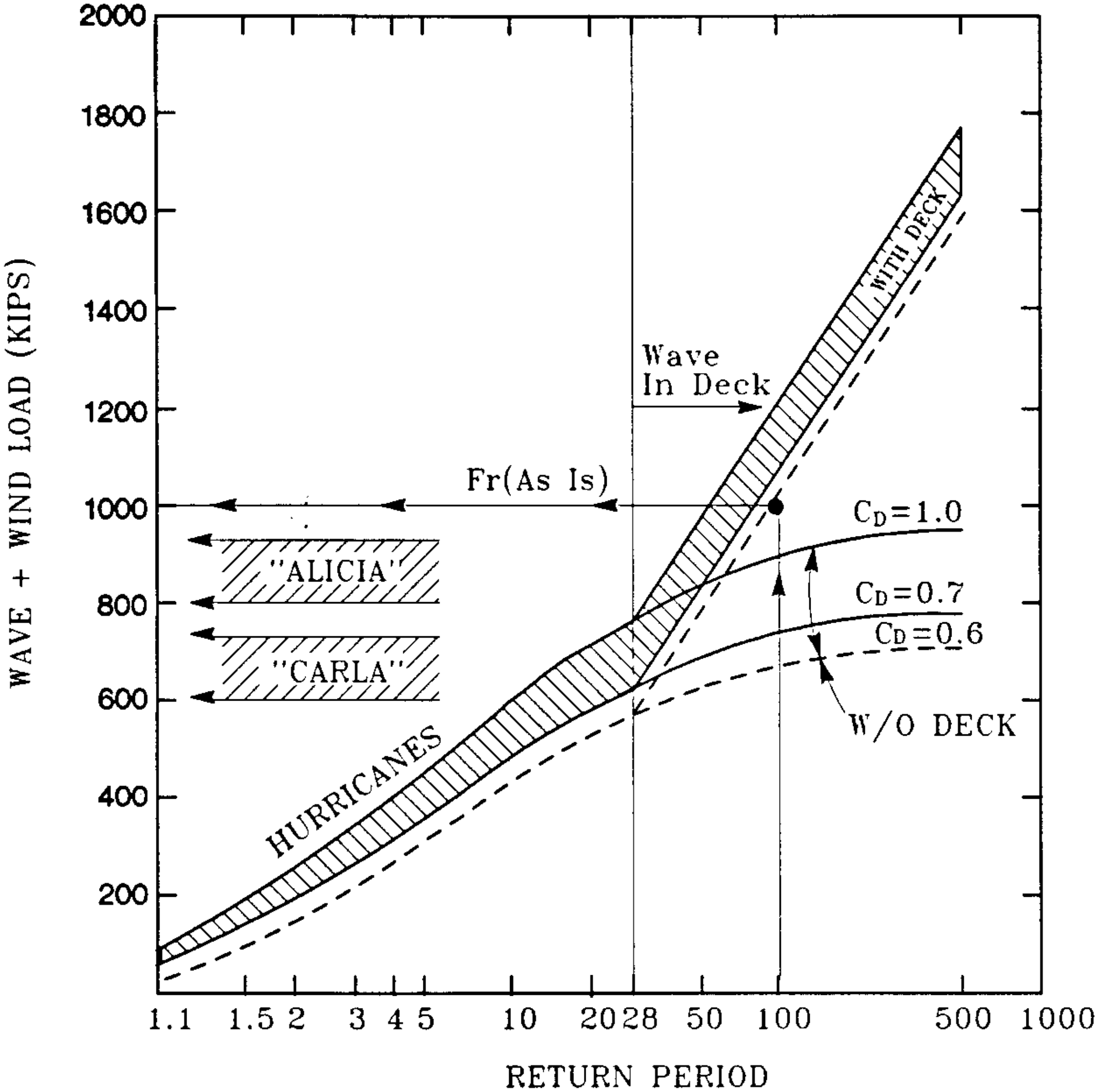


Figure 5-12 **Platform "B" Hurricane Expected Maximum Total Lateral Forces (Wind, Wave, Current) and Return Periods**

PMB Systems Engineering Inc. San Francisco. Calif. 94111

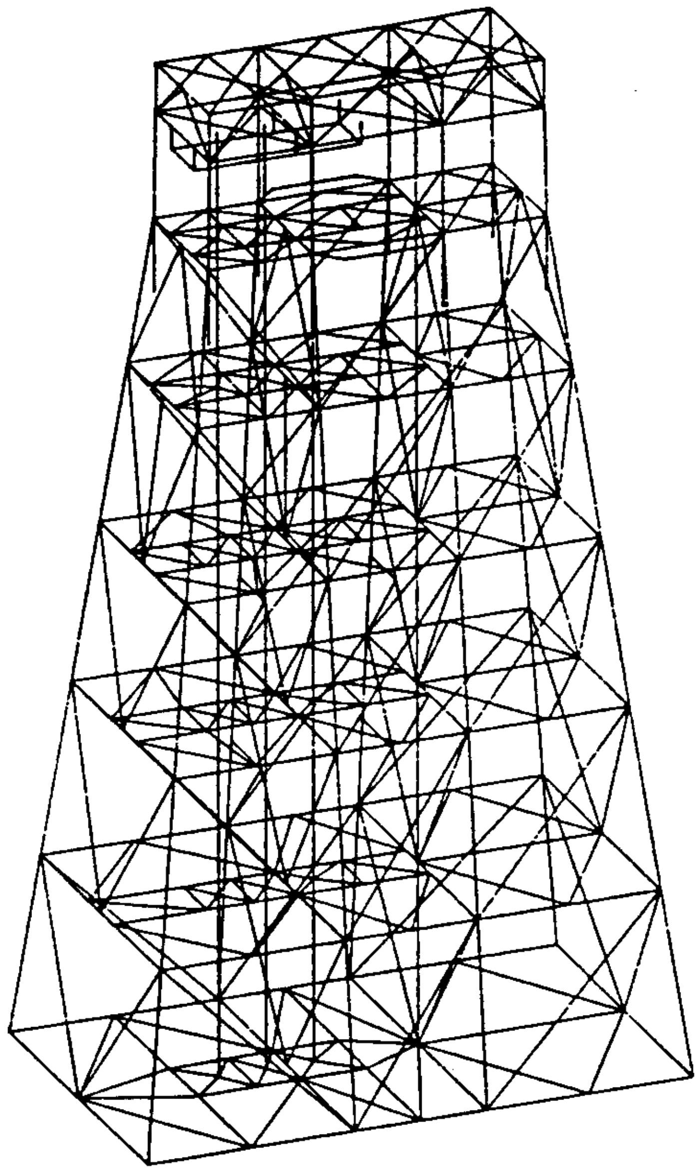
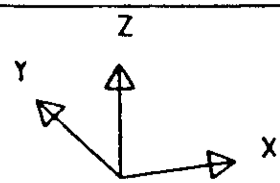


Figure 5-13 Calibration Platform "C"



GLOBAL AXES

JOINT INDUSTRY PROJECT AIM-3

271' W/D TOWER: GENERAL VIEW

SEARISER Version 2.0

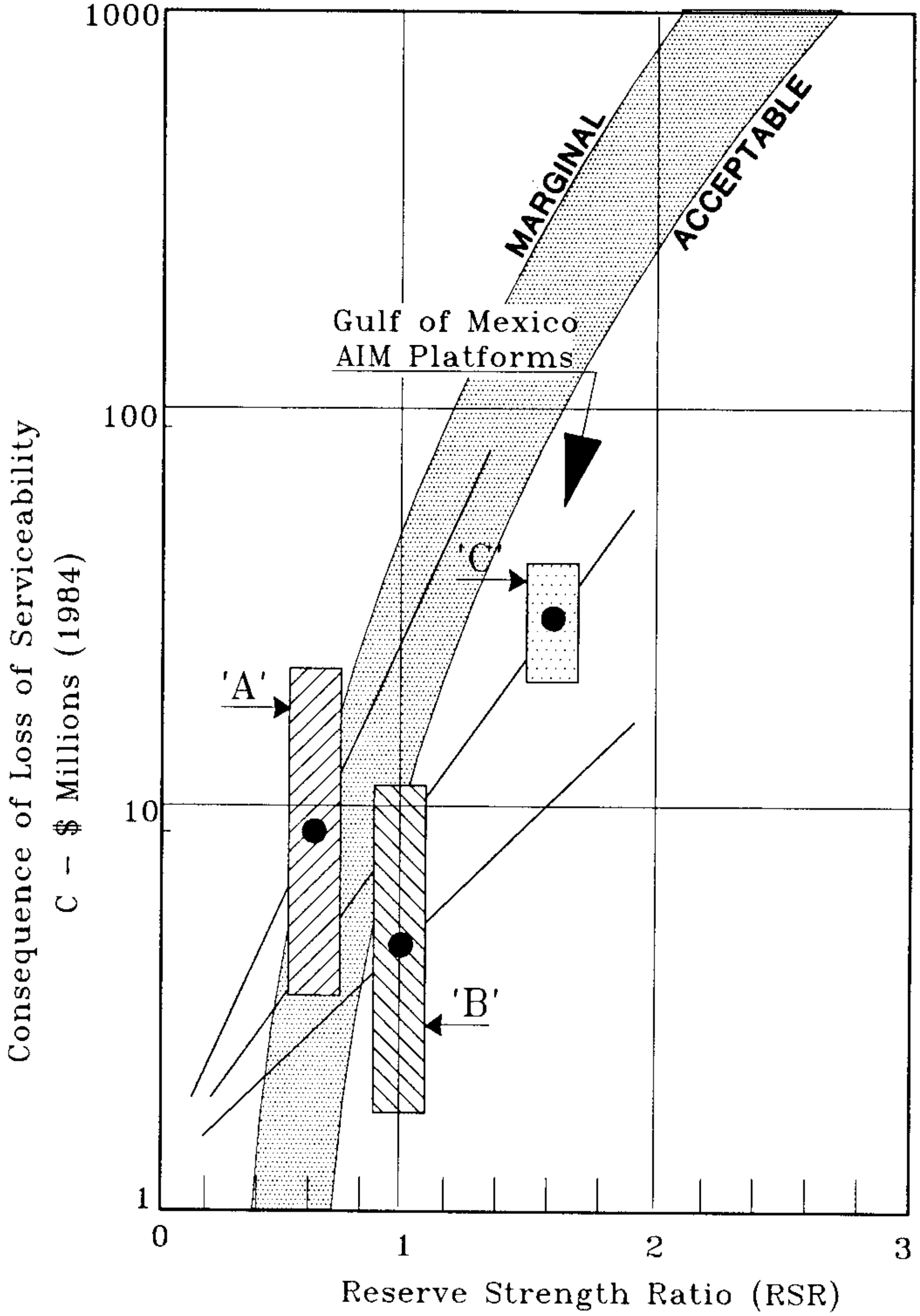


Figure 5-14 RSR versus Consequences Based On AIM Platform Calibrations

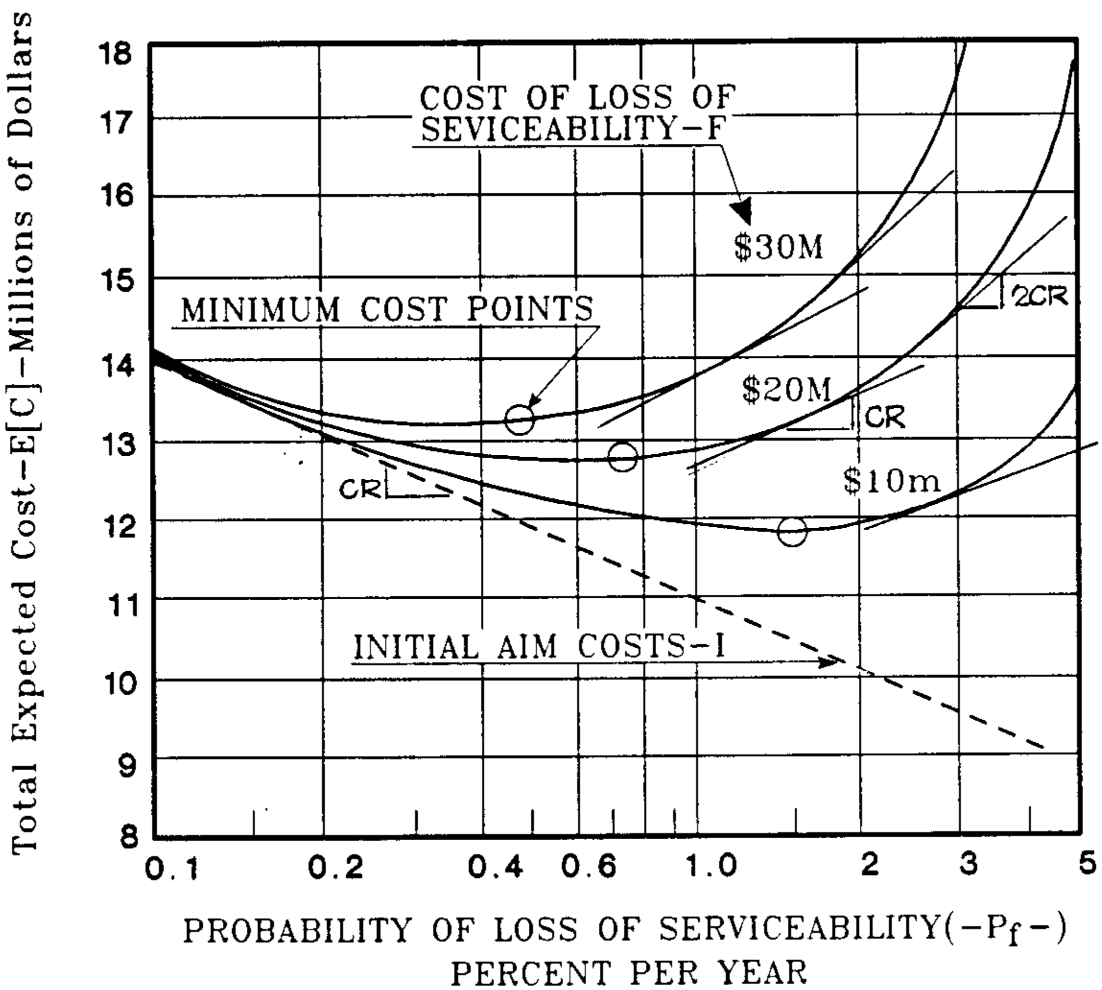


Figure 5-15 Example Results of AIM Cost - Likelihood of Loss of Serviceability Valuation

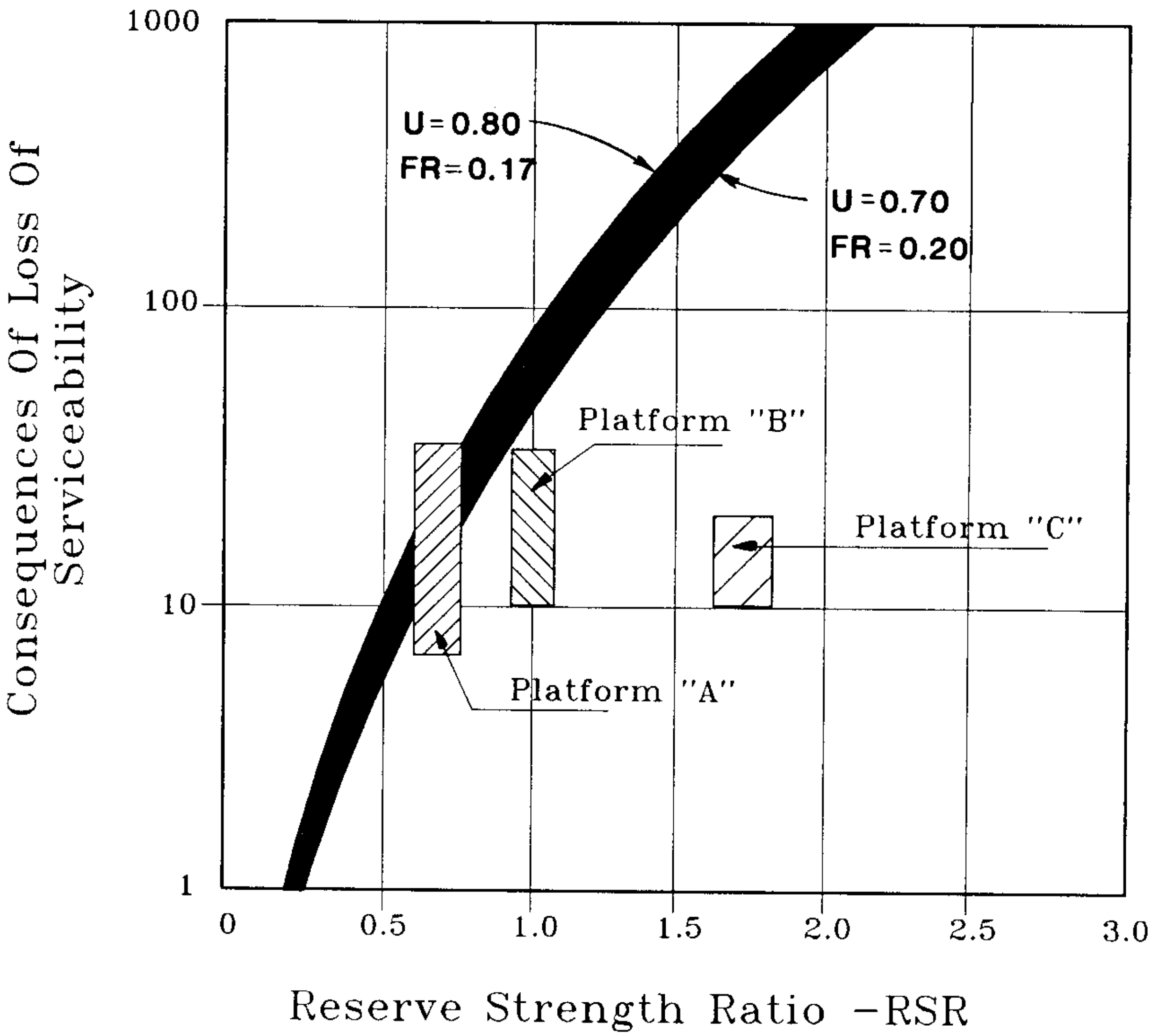


Figure 5-16 Consequences Measure (C = AIM Cycle time x Cost Ratio) versus RSR based on Cost-Benefit Valuation and Calibration Cases

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FIG-31.DRW

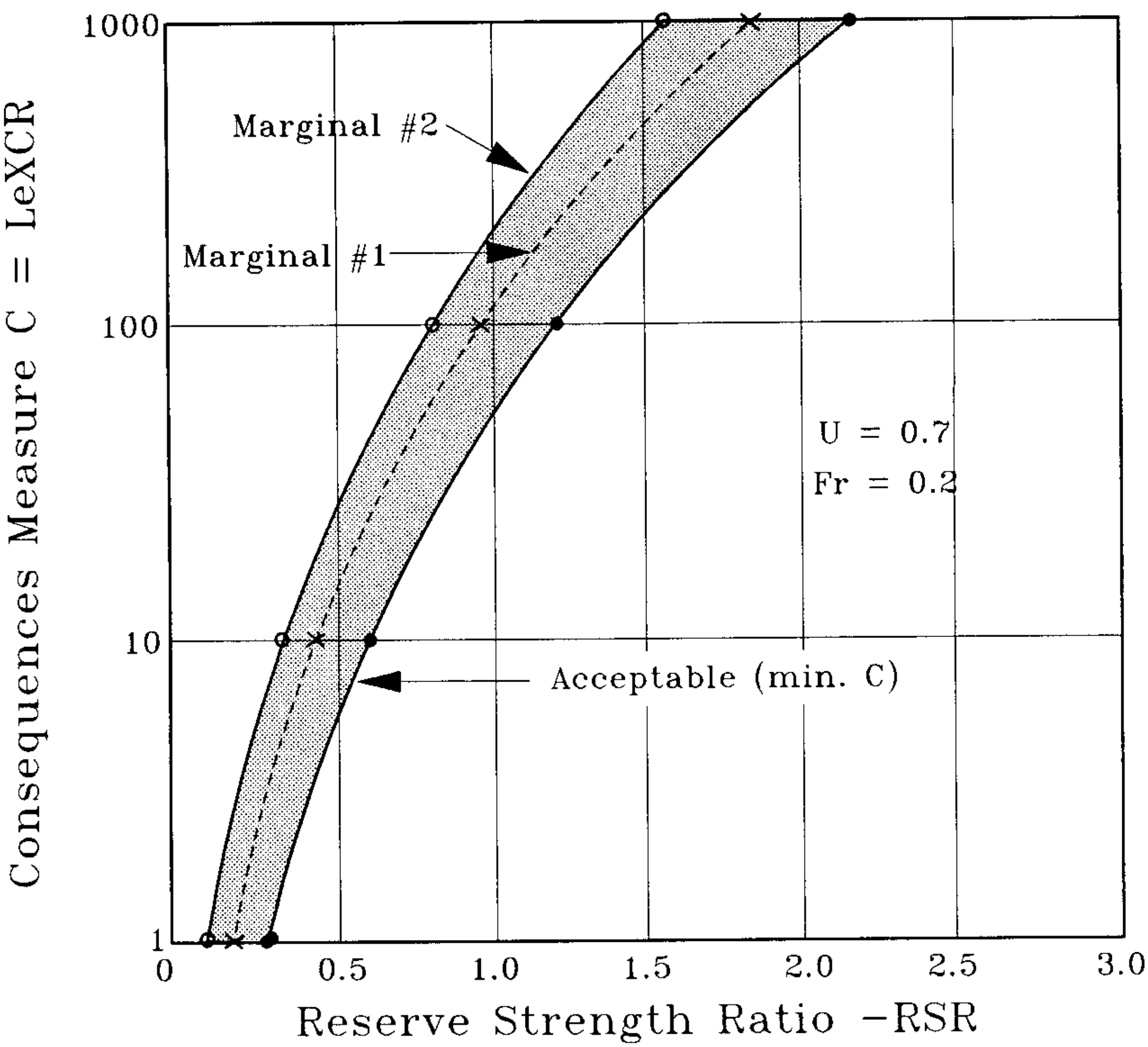

Figure 5-17 **Cost-Benefit Valuation of Consequences for Example Uncertainty Measure (U = 0.7) and Force Ratio (FR = 0.2) for Acceptable and Marginal Conditions**

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/AIM/CHRTS
FIG-D.DRW

6.0 RSR EVALUATIONS FOR MANNED PLATFORMS

Unlike the Gulf of Mexico where platforms have been commonly evacuated in advance of severe hurricanes, there are many offshore areas where the platforms cannot be evacuated in advance of severe loadings. Examples include platforms in intense earthquake regions (e.g. offshore California) and ice loading regions (e.g. Cook Inlet, Alaska, Beaufort Sea).

In these instances, the potential for human injuries exists, and the influence of these potential injuries must be evaluated in determining acceptable RSR's for the platforms involved. In general, these platforms will have consequences (Figure 3-1) that are in the "high" category of consequences of loss of serviceability.

Several approaches have been developed to address safety or reliability issues for structures having potentials for injuries. Examples include dams, bridges, buildings, and offshore platforms [19,23,26]. These approaches can be organized into three general categories:

1. Economic valuations in which potential injuries are assessed in monetary units [23].

2. Utility valuations in which potential injuries are assessed in nondimensional negative utility units [20]. Other kinds of impacts are addressed in a similar manner, and the utility units combined to define the alternative having the highest utility [22].

3. Separate valuations in which potential injuries are assessed on the basis of history, experience, and calibrations with other types of activities [23,24]. This category will be termed Experience valuations.

Each of these approaches will be illustrated and discussed in the following sections. As for many of the alternative approaches to evaluating consequences previously discussed, these alternatives should be viewed as complimentary. They should all be employed, their results considered, and used where most appropriate in communicating evaluations of consequences associated with platform AIM programs.

6.1 Economic Valuations

The economic valuation is basically an extension of the cost-benefit utility approach discussed in Section 5 of this report. The potential costs associated with injuries ($E(CF_i)$)are computed as follows:

$$E(CF_i) = (NE)(C_i)(P_i) \tag{20}$$

where NE is the number of personnel exposed on the platform, C_i are the costs associated with the potential injuries, and P_i is the likelihood of serious injuries to the personnel given a platform loss of serviceability.

For example, if there were 100 personnel exposed on a high consequences platform that needed to be requalified, the average costs associated with the potential injuries was $1 million per injury (Figure 1-2), and the likelihood of serious injury given a loss of serviceability was 80 percent, then the expected potential costs associated with injuries would be $80 million. This cost would be added to the other potential costs associated with the platform's loss of serviceability, and evaluated as outlined in Section 5.3.

Continuing this example, if the platform, facilities, and wells represented an expected cost in the range of $300 to $400 million ($380 million to $480 million including potential injuries), the AIM cost required to decrease the likelihood of platform loss of serviceability was $50 million, and the platform AIM cycle length was 5 years, the Consequences Measure C = 38 to 48 (Figure 5-17), (CR = CF/CI = 380/50 = 7.6; C = LE * CR = 5 * 7.6 = 38)). For a Force Ratio, FR = 0.2 and Uncertainty Measure, U = 0.7, RSR's in the range of 0.6 ("marginal") to 1.0 ("acceptable") would be indicated to requalify the platform.

Given this approach, there are several key issues. The first is the recognition that the approach is not one that places a value on injuries. Rather, it is an approach that evaluates how much resource (expressed in monetary terms) should be spent on reducing the likelihoods of serious injuries.

The second key issue is that resources can be devoted to reducing either the numbers of personnel exposed (e.g. remotely controlled operations) or the likelihood of serious injuries (e.g. life saving equipment and training). In addition, the likelihood of serious injuries can be reduced by reducing the chance of explosion, blowout, or fire in the event of platform failure. Thus, making the platform stronger (increasing the RSR) may be the least efficient way to manage this hazard.

The third key issue is to define the costs associated with potential injuries, CF_i. There are four categories of approaches to define CF_i:

1. Productivity potential - given a serious injury, to evaluate the loss in goods and services production of that injury to society (Figure 6-1) [23].

2. Historical implicit value - this value is determined by examining what the public and private expenditures have been to determine safety for both involuntary (public) and voluntary (private) activities (Figures 6-2 and 6-3) [26,27]. Expenditures are money spent in the course of conducting the activities shown.

3. Judicial value - this value is based on what the legal and insurance systems have awarded to individuals in the case of

serious injury (Figure 1-2) [23]. The values shown in Figure 1-2 have been based on legal and insurance payments in the case of death associated with the failure of the facilities shown.

4. Personal value - this value is based on what individuals choose to invest in the form of insurance to lower risks and on what individuals are compensated to take additional risks in their activities (Figures 6-4 and 6-5) [26,27].

Evaluation of productivity potential (Figure 6-1, 12 years school, 25 to 35 years age group, in 1988 dollars) would equate to about $750,000 per injury. Results from the other approaches develops costs (1988 dollars) in the range of $500 thousand to $5 million per serious injury.

6.2 Utility Valuations

A utility based approach to assessment of AIM program potential consequences was outlined and illustrated in the AIM I report [1]. In this approach, the consequences for potential serious injuries (Figure 6-6) are evaluated in terms of a nondimensional utility unit (U_2). The evaluators must define a relationship between the number of injuries and this utility unit (note that the functional form shown in Figure 6-6 [20] is very nonlinear and risk adverse).

Similarly, the evaluators must define relationships between the utility unit and other potential categories of consequences (e.g. dollar costs and environmental impacts expressed in terms of barrels of oil spilled). As a final step, the evaluators must define weightings (trade-offs) that will allow combination of the categories of likelihood weighted utilities [20,22].

This approach embodies many of the same aspects and problems associated with an explicit monetary valuation. However, it does avoid explicit discussion of the monetary costs and benefits associated with decreasing the likelihoods of serious injuries. Development of the functional relationships between utility units and consequences and the preference structure expressing trade-offs between the different categories of consequences pose major challenges in implementing this approach [20,1].

6.3 Experience Valuation

An experience based approach to evaluating the consequences associated with potential injuries has been applied previously in backgrounding design criteria for North Sea platforms in which evacuation of personnel in advance of severe storms was not feasible (Figure 6-7) [24]. In this approach, the expected rate of serious injuries during the platform lifetime was evaluated for a range of likelihoods of loss of platform serviceability. The expected rate of injuries was compared with rates of serious injuries that had been accepted in the recent past by individuals (voluntary) and the public (involuntary) [26,27,28].

The platform target reliability was based on the dual considerations of economics and the range of voluntary potential injuries [24]. The voluntary serious injury risk range was 0.1 to 1 serious injury per platform year. Based on the expected number of serious injuries given a platform loss of serviceability (Figure 6-7), the target reliability for the lower end of the voluntary range was 99.5 to 99.7 percent per year. If there were an expected life loss given a failure of 100 man-years per year of hazard exposure, then the target reliability would be 99.9 percent per year.

For the upper range of voluntary rates, the likelihoods of loss of platform serviceability would be increased by a factor of 10.

The next paragraphs will illustrate how this information might be used to determine acceptable RSR ranges for the example platform (conventional 8-leg drilling and production platform) located in the central North Sea [24].

Estimates (based on calibrated historic storm hindcast results) were made for the annual expected maximum wave heights, $\hat{H}_m$ (Figure 6-8). The 100-year $\hat{H}_m$ = 90 feet. The Coefficient of Variation of the $\hat{H}_m$'s, V_h = 12 percent (Equations 8,9). The wave height exponent for the platform, α = 1.85 (Figure 6-9, Equation 6), and the force uncertainty measure, U_f = 0.22.

The Force Ratio, F_r = 0.6 (Equation 7). This result is confirmed by the characterization of the likelihoods of the maximum total wave (includes currents and winds) forces acting on the platform (Figure 6-10, Equation 3) FR = F_{50}/F_{99} = 5000 kips / 8300 kips = 0.6. Note also that U_f = 0.22 is confirmed by the expected annual maximum force characterization (Figure 6-10).

If the assessment of uncertainties associated with evaluations of the forces is recognized (Figure 6-11), V_{cf} = 0.42 (Equation 10). When the Type II uncertainty (due to modeling errors) is added to the Type I uncertainties (natural or inherent variabilities), the resultant Coefficient of Variation of the expected annual maximum total force increases to V_f = 0.48 (Equation 10), the Force Ratio, F_r = 0.3 (Figure 6-10), and the force uncertainty measure, U_f = 0.45 (Equation 9).

As discussed in Section 5.1, when the basis for evaluations are actuarial or experience based, the analysis reasonably should exclude modeling or analysis uncertainties. Consequently, in the remainder of this illustration, only natural or inherent variabilities will be included. Thus, F_r = 0.6, U_f = 0.22.

The next step is to develop an estimate of the platform capacity Type I variabilities (Figure 6-12). Based on these results, U_r = 0.20 and V_r = 0.21. The resultant uncertainty measure, U = 0.30 (Equation 12).

Safety Indices, B, can be computed (Equation 4) for each of the likelihoods of loss of platform serviceability (Figure 6-7) at the lower and upper limits of voluntary risks of serious injury. Then these B's, FR = 0.6, and U = 0.30 can be used to determine the associated RSR's (Equation 2, Figure 6-12, 50th percentile).

For the lower voluntary range, RSR's of 1.4 to 1.7 are indicated for 50 to 200 expected serious injuries given a platform loss of serviceability (Figure 6-13). These RSR's might be associated with new construction. Note that for the example platform, the design RSR = 2.5 (Figure 6-12).

For the upper voluntary range, RSR's of 1.0 to 1.3 are indicated for 50 to 200 expected serious injuries given a platform loss of serviceability. These RSR's might be associated with requalifications of existing platforms.

A similar approach can be based on the information published by Whitman [19] (Figure 1-2). The "acceptable" and "marginal" likelihoods of platform loss of serviceability associated with different numbers of expected serious injuries can be computed from Equations 13 and 14 (replace millions of $ with expected number of serious injuries). Then using the North Sea platform example FR = 0.6 and U = 0.3, the associated RSR's can be determined (Figure 6-14).

The two approaches produce very comparable results (Figures 6-13 and 6-14). For 50 to 200 expected serious injuries given a platform loss of serviceability, the "acceptable" RSR's are in the range of 1.5 to 1.6, and the "marginal" RSR's are in the range of 1.2 to 1.4.

Also, it is interesting to note how these RSR's correlate with those from a cost-benefit utility analysis (Section 5.3). The "acceptable" and "marginal" likelihoods of loss of platform serviceability based on the cost-benefit evaluation of this North Sea platform ranged from 0.5 to 1.5 percent per year (minimum cost points, Figure 5-15). These likelihoods translate to Safety Indices of 2.6 to 2.2. Given FR = 0.6 and U = 0.3, the RSR's (Equation 2) = 1.2 ("marginal") to 1.3 ("acceptable"). The cost-benefit evaluation based RSR's are in the same range as those from the parallel consideration of potential serious injuries to operating personnel.

Marshall [25] has pursued a similar experience based approach to evaluate the implications of potential serious injuries in determining platform reliability (Figure 6-15). Actuarial data on the number of serious injuries per incident and the rates of occurrence of those numbers has been compiled for a wide variety of activities and structure/facility operations. Two general categories of activities were evaluated, voluntary and involuntary. Broad bands were drawn to relate the categories of activities to the numbers of injuries to the likelihood of these injuries. Note that the likelihoods are based on a one-year exposure time to the activity or hazard of concern.

If one were to evaluate the platform operating personnel exposure as voluntary, and bracket the numbers of potential serious injuries defined by coal mining (20 to 30 serious injuries per incident) and commercial aircraft activities (80 to 120 serious injuries per incident), the likelihood of platform loss of serviceability would be about 1 percent. Given the North Sea platform example, this risk rate would translate to a B = 2.33, and RSR = 0.6 exp (2.33 x 0.3) = 1.2. This result is very comparable with those shown in Figures 6-13 and 6-14.

The Canadian Standards Association (CSA) has issued guidelines for the development of limit state design for offshore platforms [29]. These guidelines specifically address life safety issues associated with platform operations. The guidelines propose the following criterion for life safety considerations based on the likelihood of loss of platform serviceability (P_{fs}):

$$P_{fs} = \frac{(TA10^{-5})}{WN^{0.5}} \tag{21}$$

where T is the life of the structure; A is an Activity Factor, W is a Warning Factor, and N is the expected maximum number of people exposed to risk. P_{fs} is the lifetime (T = exposure period) likelihood of loss of the platform serviceability.

The term $N^{0.5}$ is an aversion factor that recognizes the proportionately greater public concern for multiple severe injury accidents than for an equivalent number of severe injuries caused singly by numerous accidents.

Activity Factors, A = 1.0 for buildings, A = 3.0 for bridges, and A = 10 for high exposure structures such as offshore platforms are suggested in the CSA guidelines [29]. Warning Factors, W = 0.01 for fail-safe conditions, 0.1 for gradual failure, and 1.0 for sudden failure without warning are also suggested.

For example, taking T = 1 year (to express P_{fs} on annual basis), A = 10, W = 0.1, and N = 100 results in Pfs = 0.01 percent per year (B = 3.8). Using the example North Sea platform information, RSR = 0.6 exp (3.8 x 0.3) = 1.9.

This RSR is somewhat greater than previously determined (Figures 6-13 and 6-14). However, it should be recognized that these guidelines are intended for the engineering of new platforms. The CSA guidelines recognize that there are two criterion that must be evaluated in reaching decisions on what constitutes adequate platform safety (from the structural standpoint), life-safety (P_{fs}) and economics (P_{fe}). When the optimum P_{fe} exceeds P_{fs}, there are considerable pressures to relax P_{fs} to arrive at a "socio-economic" optimum. In general, this is precisely the case for requalification of high consequence platforms.

Recognition of the difference between design of new platforms and requalification of existing platforms might be developed by using a Warning Factor, $W = 0.01$ (based on the performance history of the structure and the continuing AIM cycles). Again taking $T = 1$ year, $A = 10$, $W = 0.01$, and $N = 100$ results in $P_{fs} = 0.1$ percent per year ($B = 3.12$), and an $RSR = 0.6 \exp (3.12 \times 0.3) = 1.5$. This RSR is much more in line with those developed from the other approaches (Figures 6-13 and 6-14).

The Worldwide Offshore Accident Databank (WOAD) has developed a detailed documentation of causes and consequences of platform operations related losses of serviceability during the period 1970 to 1985 [30]. Table 6-1 [31] summarizes the causes of severe accidents in five categories. Figure 6-16 [31] portrays this information graphically.

On fixed offshore platforms (FOP's) blowouts and fires account for 48 percent of all severe accidents. Severe accidents are defined as accidents resulting in either total loss, irreparable damage, or severe damage to platform components or members. Accidents directly relating to the structure (environment, other structural) account for 12 percent of the incidents (excluding collisions, Figure 6-16a).

In the case of jack-up platforms (JU's), the percentage of accidents due to structural failure is much higher (Figure 6-16b) (34 percent, excluding collisions). The CSA evaluation indicates that this is principally because of a higher rate of accidents related to material problems (steel and foundations), inadequacies in design/analysis, and uncertainties regarding environmental loads (designs not site specific).

The causes of serious accidents on fixed offshore platforms in the North Sea and Gulf of Mexico have been analyzed on the basis of the number of wells supported by the platform [32] (Figure 6-17). As might be expected there is a higher percentage of serious or severe accidents on platforms having greater numbers of wells.

It is clear that non-structure capacity related accidents dominate the hazards. The total hazards are dominated by blowouts, collisions, explosions, and fires. This fact recently was brought to worldwide attention by the fire and explosion aboard the Piper A platform in the North Sea. Of some 200 operating personnel onboard Piper A, some 170 perished or received severe injuries in the fire and explosion.

Perhaps the most important aspect of the WOAD data bank concerns the consequences of platform accidents (Figure 6-18) [30]. Of 134 serious accidents on all types of fixed offshore platforms (worldwide) in a 14-year time period, 16 percent resulted in loss of life. Most importantly, none of these accidents was caused by structural loss of serviceability. All were caused by explosion, fire, or blowout.

To date, there has not been one severe injury or fatality that has resulted from a failure of a platform or structural component. Indeed, this is an enviable life-safety record for offshore platforms. The objective of AIM RSR - consequence evaluations is to help maintain this high standard of performance.

To conclude this section, another high consequence platform example will be developed (Figure 6-9). The example platform is located in Cook Inlet, Alaska. The platform has experienced a blowout that resulted in undermining the piles in one corner of the platform.

The proposed AIM program for this platform consists of an extensive condition survey of the structure, foundations, and soils; filling the blowout crater with gravel to re-establish the foundation's lateral capacity; and installing drilled and grouted inserts in the piles to re-establish their axial capacity. The platform is proposed for a 5-year AIM cycle and has a 10-year remaining economic life. The platform will be manned (50 personnel) for year-round operations.

Extensive studies have been performed of the ice and earthquake environments that potentially subject the platform to extreme loadings (Figure 6-20). The 100-year design load for the platform was 8,500 kips. The ice loading Uncertainty Measure, U_i = 0.30, and Force Ratio, F_{ri} = 0.49. The earthquake loading Uncertainty Measure, U_q = 0.68, and Force Ratio, F_{rq} = 0.19.

Push-over analyses have been performed for the critical loading conditions (Figure 6-21) and the repaired platform. The differences in the Ultimate Limit State resistances is due to the differences in earthquake and ice loading patterns acting on the platform. The ULS capacity for the ice loading pattern, R_{ci} = 12,000 kips. The ULS capacity for the earthquake loading pattern, R_{cq} = 15,500 kips. The platform capacity Uncertainty Measure will be assumed as U_c = 0.2.

The ice loading Reserve Strength Ratio, RSR_i = 1.4. The earthquake loading Reserve Strength Ratio, RSR_q = 1.8.

The question is, "is the proposed AIM program for this structure acceptable?" Stated in the RSR - consequences context, "is the combination of RSR and consequences such that the platform is qualified or suitable for service?"

The first approach is to make a cost-benefit utility valuation (Utility Approach, Section 5.3). The total costs associated with a loss of platform serviceability are estimated to be \$350 million to \$450 million (includes platform salvage, severe injury, and pollution abatement costs). The AIM program costs required to decrease the likelihood of the platform loss of serviceability by a factor of 10 are estimated to be \$30 million to \$40 million. The Cost Ratio, CR = 11 to 12 (use CR = 12). The Present Value Function , PVF = 5. The Consequences Measure, C = CR x L = 60. These results indicate that the platform potential consequences fall in the upper portion of the moderate category (Category II).

The optimum or "acceptable" (lowest total expected initial and future costs) Safety Index, B_a = 2.5 (Equation 18). The "acceptable" likelihood of loss of platform serviceability, P_{fa} = 0.7 percent per year (Equation 4). Using B_a = 2.5, and the Force Ratios and Uncertainty Measures previously cited, the "acceptable" RSR is about 1.2.

The "marginal" (total cost of loss of serviceability curve reaches a slope equal to twice that of the initial cost curve) Safety Index, B_m = 2.0. The "marginal" likelihood of loss of platform serviceability, P_{fm} = 2.2 percent per year. Again using the Force Ratios and Uncertainty Measures previously cited, the "marginal" RSR is about 1.0.

On the basis of the Utility Approach used, the platform AIM program RSR's are clearly acceptable.

The second approach to be used is the Experience Valuation (Section 6.3) basis for addressing implications of potential severe injuries associated with this manned platform. In the case of a loss of serviceability incident, an 80 percent severe injuries rate will be presumed (50 personnel x 0.8 = 40 severe injuries). At the lower limit of the voluntary range (Figure 6-7), the likelihood of platform loss of serviceability, P_{fs} = 0.25 percent per year (B_s = 2.8). At the upper limit, P_{fs} = 2.5 percent per year (B_s = 2.0).

Based on the Force Ratios and Uncertainty Measures cited, RSR's in the range of 1 ("marginal") to 1.4 ("acceptable") would be indicated.

On the basis of the Experience Valuation approach used to address potential severe injuries, the platform AIM program RSR's are acceptable.

In this particular case, the platform is exposed to two significant environmental loading hazards; from ice and earthquakes. The following will illustrate how the two effects can be addressed.

The platform likelihood of loss of serviceability under ice loadings, P_{fi}, can be estimated by finding the Average Return Period of the ice loading that brings the platform to its ULS for ice loading patterns: RP_{ci} = 3,330 years (Figure 6-20). Thus, $P_{fi} = RP_{ci}^{-1}$ = 0.03 percent per year.

Similarly, the likelihood of loss of platform serviceability under earthquake induced loadings, P_{fq}, can be estimated. RP_{cq} = 1,250 years (Figure 6-20). Thus, P_{fq} = 0.08 percent per year.

The two loading conditions can be considered to be essentially independent (occurrence of one does not influence likelihood of occurrence of other). The likelihoods of simultaneous extreme ice and earthquake loadings can be reasonably ignored [10]. Thus, the total likelihood of loss of platform serviceability, $P_{ft} = P_{fi} + P_{fq} = 0.11$ percent per year. This equates to an annual Safety Index, $B = 3.1$ for the platform.

The cost-benefit utility valuation indicated "acceptable" and "marginal" Safety Indices of 2.5 and 2.0, respectively. The experience based valuation of potential injuries indicated comparable Safety Indices of 2.0 to 2.8. The platform clearly meets these standards.

TABLE 6-1

CAUSES OF SEVERE ACCIDENTS [31]

Cause of Accident (%)	All FOPS Except JU 1970-84 Worldwide (Fig. 6-16a)	JU only 1970-83 Worldwide (Fig. 6-16b)	All FOPS - 1980-84 North Sea	All FOPS - 1980-84 Gulf of Mexico
1. Structural Failure	27	47	16	22
2. Operational Mishap	48	24	48	57
3. CTIM*	15	21	20	15
4. Leakage	6	2	8	2
5. Other	4	6	8	4
All Accidents	100	100	100	100

*CTIM: Construction, Transportation, Installation, Mobilization

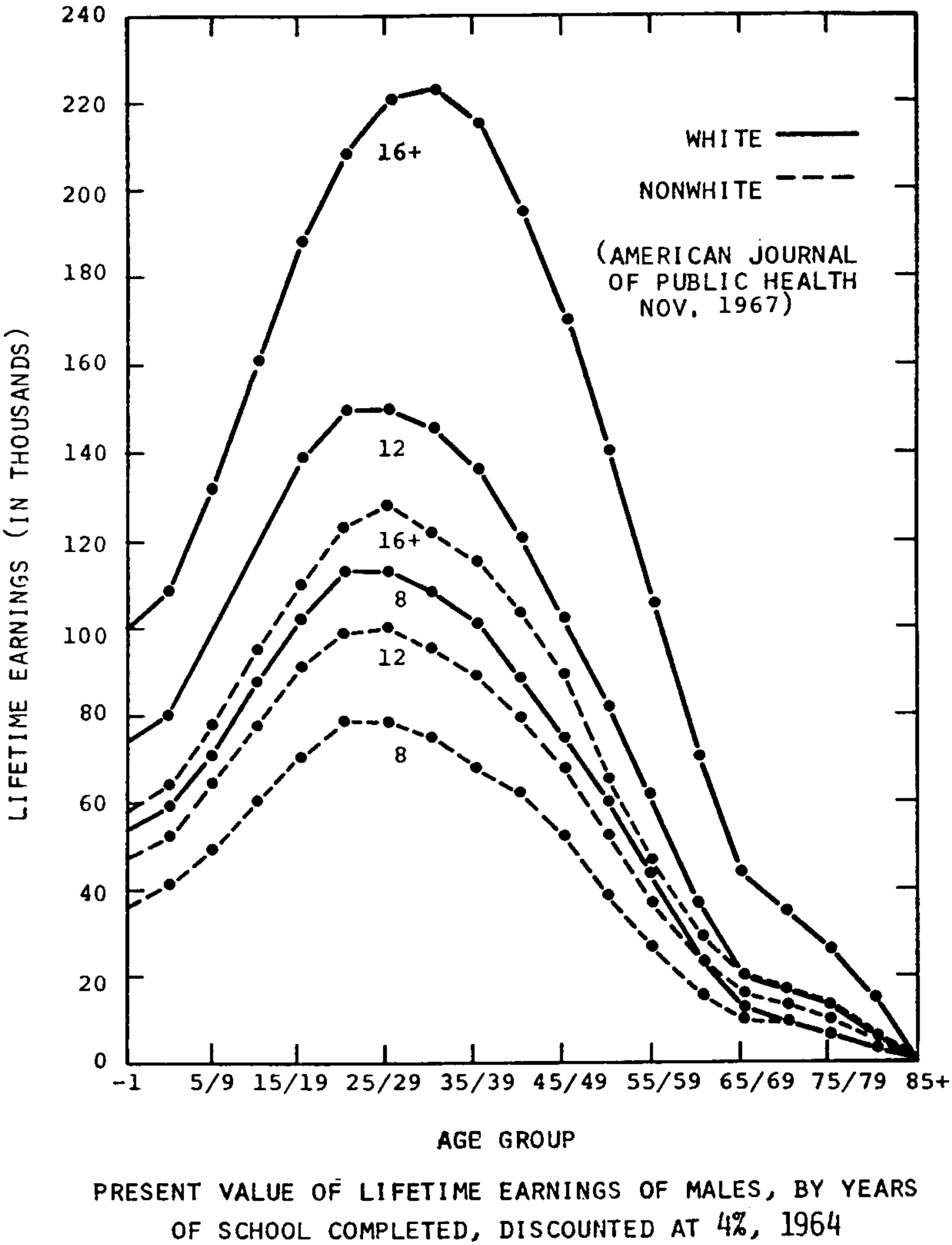


Figure 6-1 **Present Value of Lifetime Earnings of Males by Years of School Completed, Discounted at 4%, 1964 Dollars**

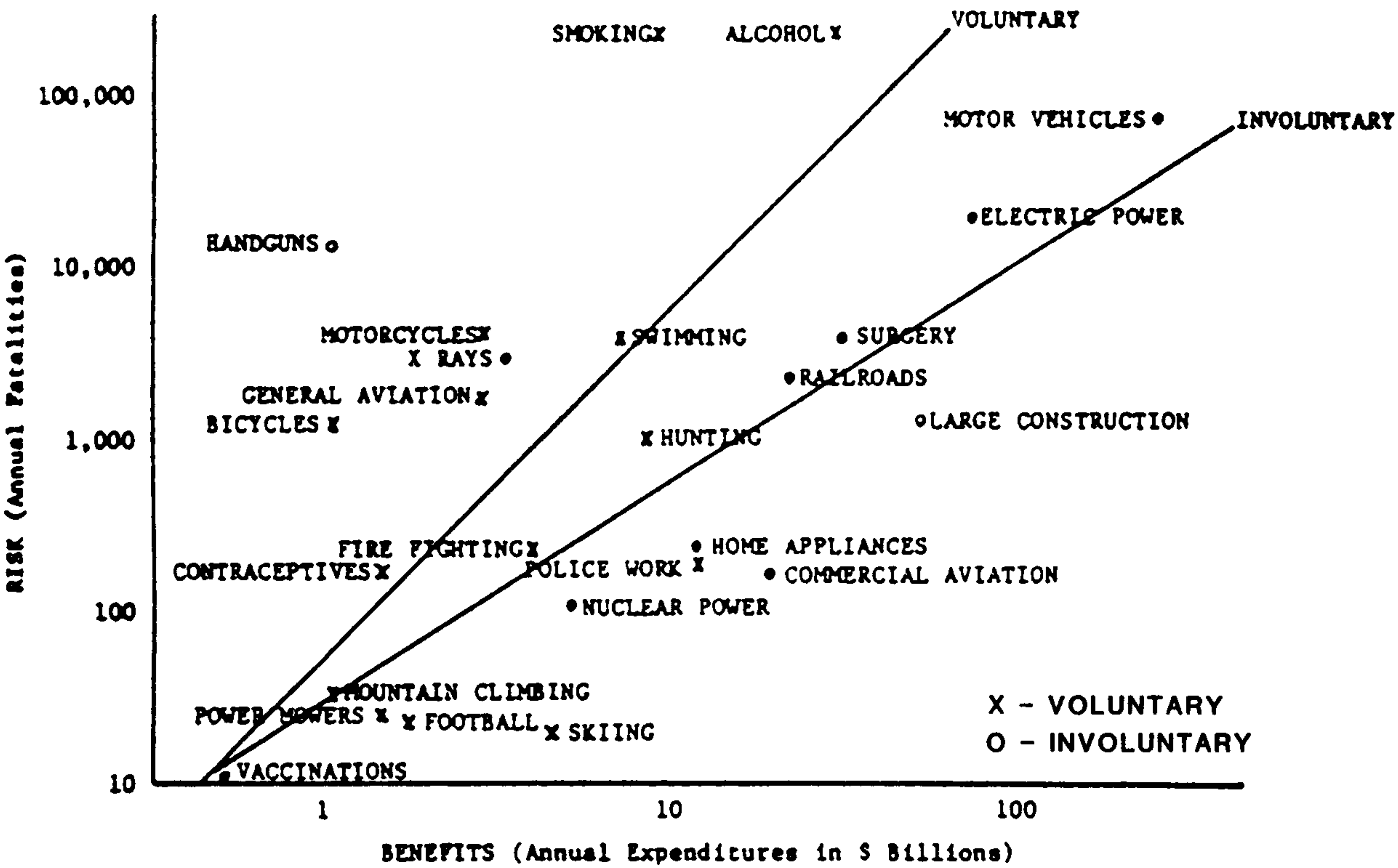


Figure 6-2 Annual Rate of Serious Injuries versus Monetary Benefits for Voluntary and Involuntary Activities Shown in Figure

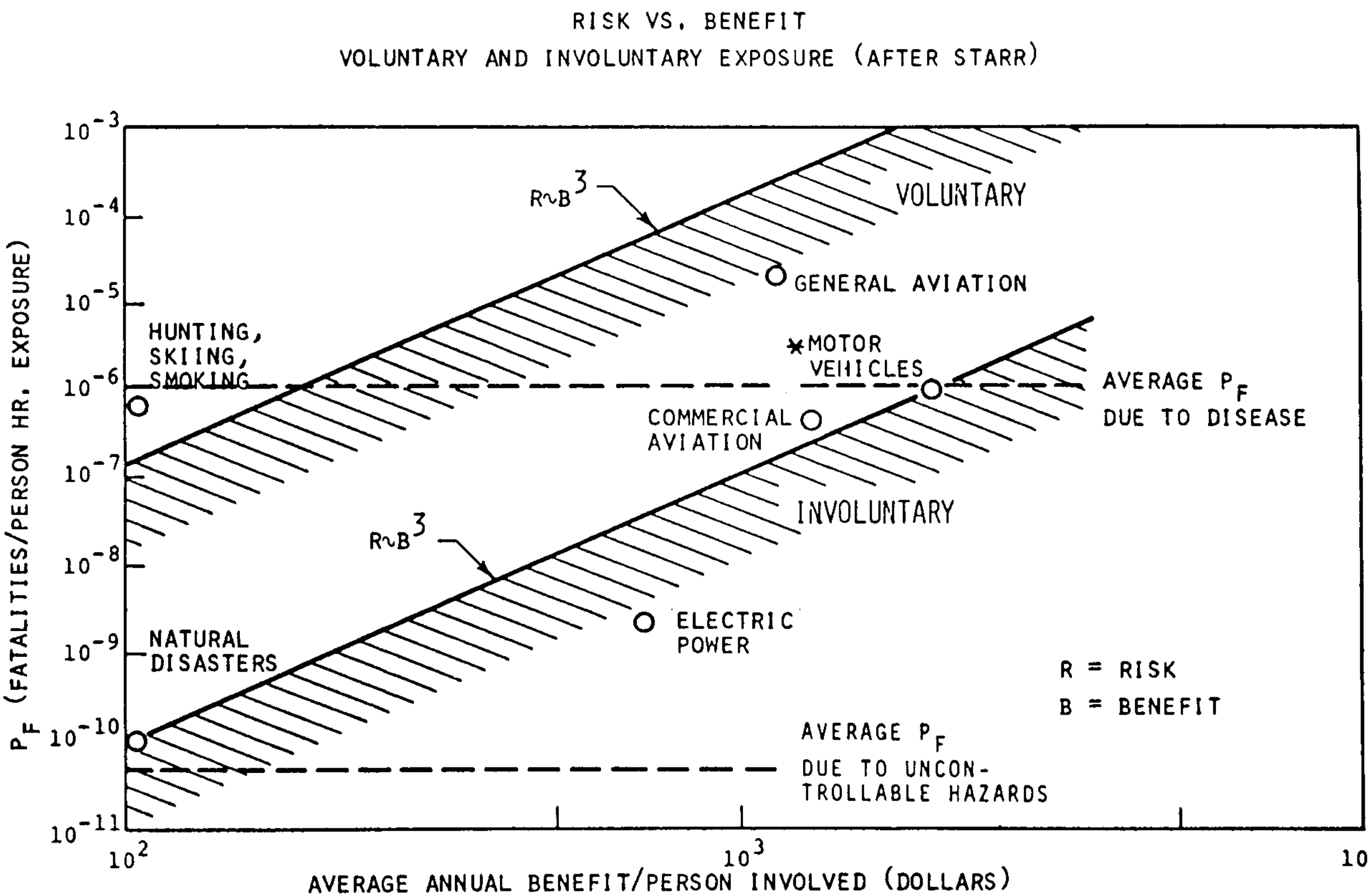


Figure 6-3 **Comparison of Risk and Benefit from Various Sources. Risk is measured by Fatalities Per Person Per Hour of Exposure. Benefits Reflects the Average Amount of Money Spent on the Acti\ or the Average Contribution of the Activity to Annual Income**

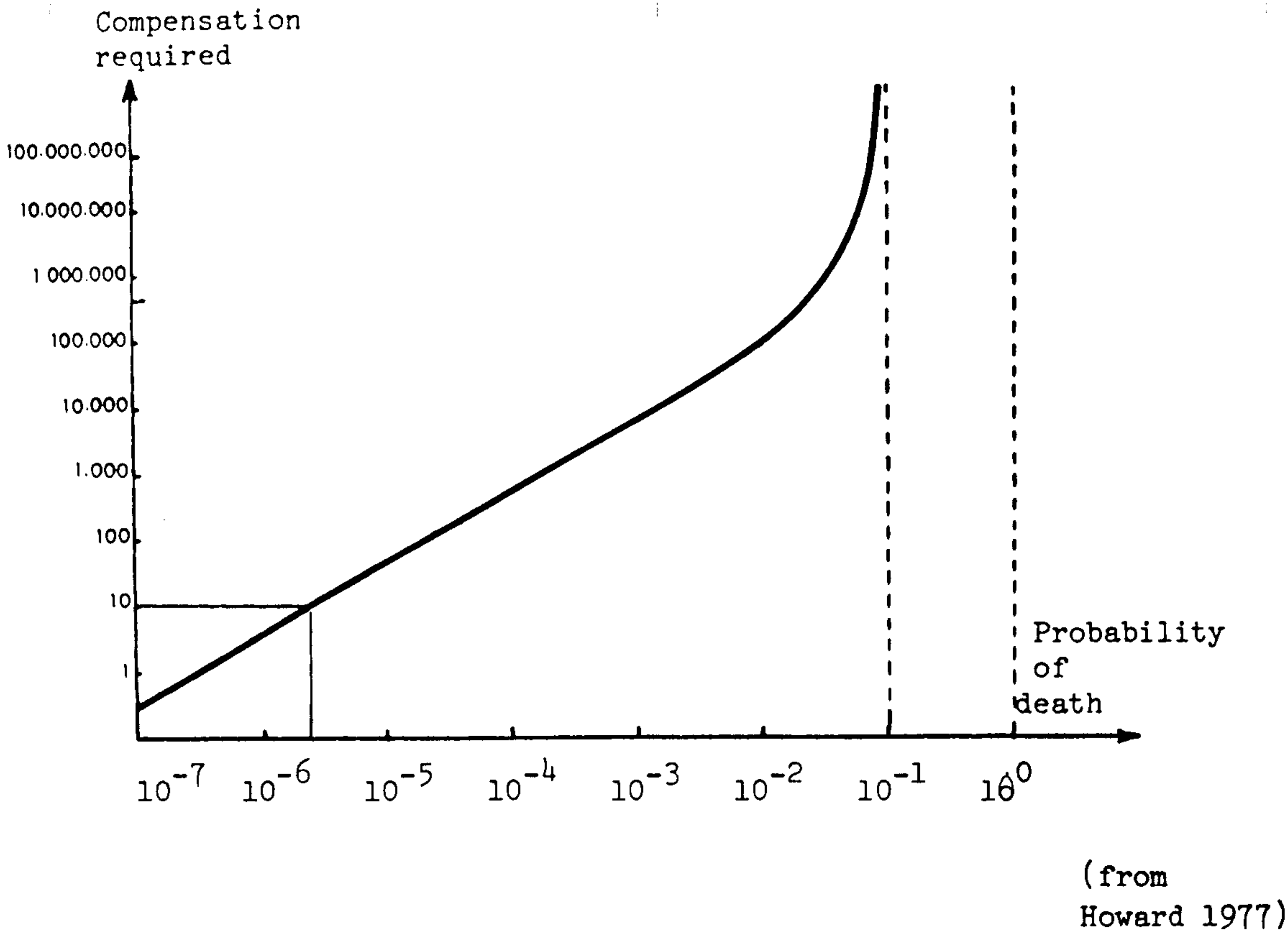


Figure 6-4 **Individual Willingness to Pay for Reduction of Serious Injury Probability**

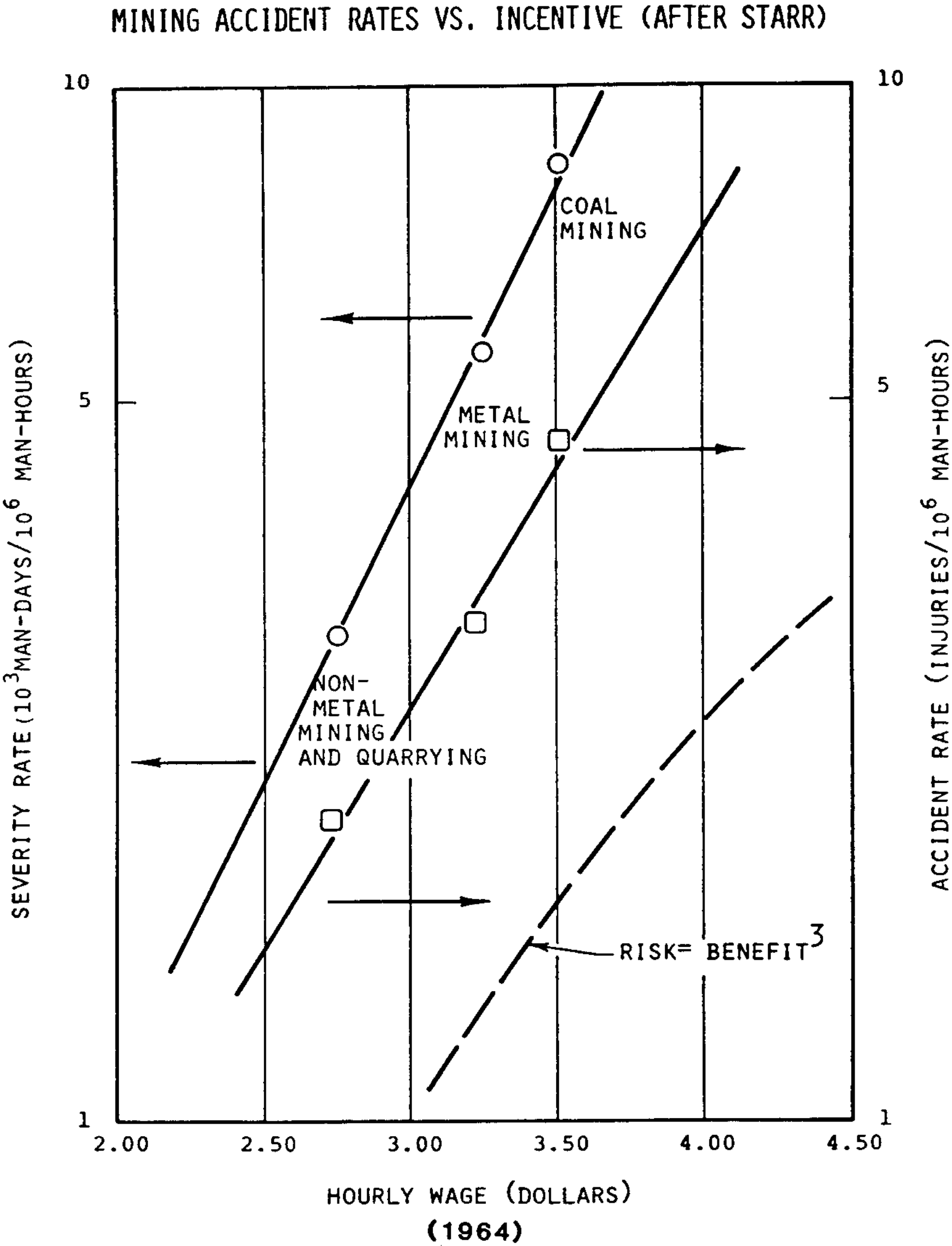
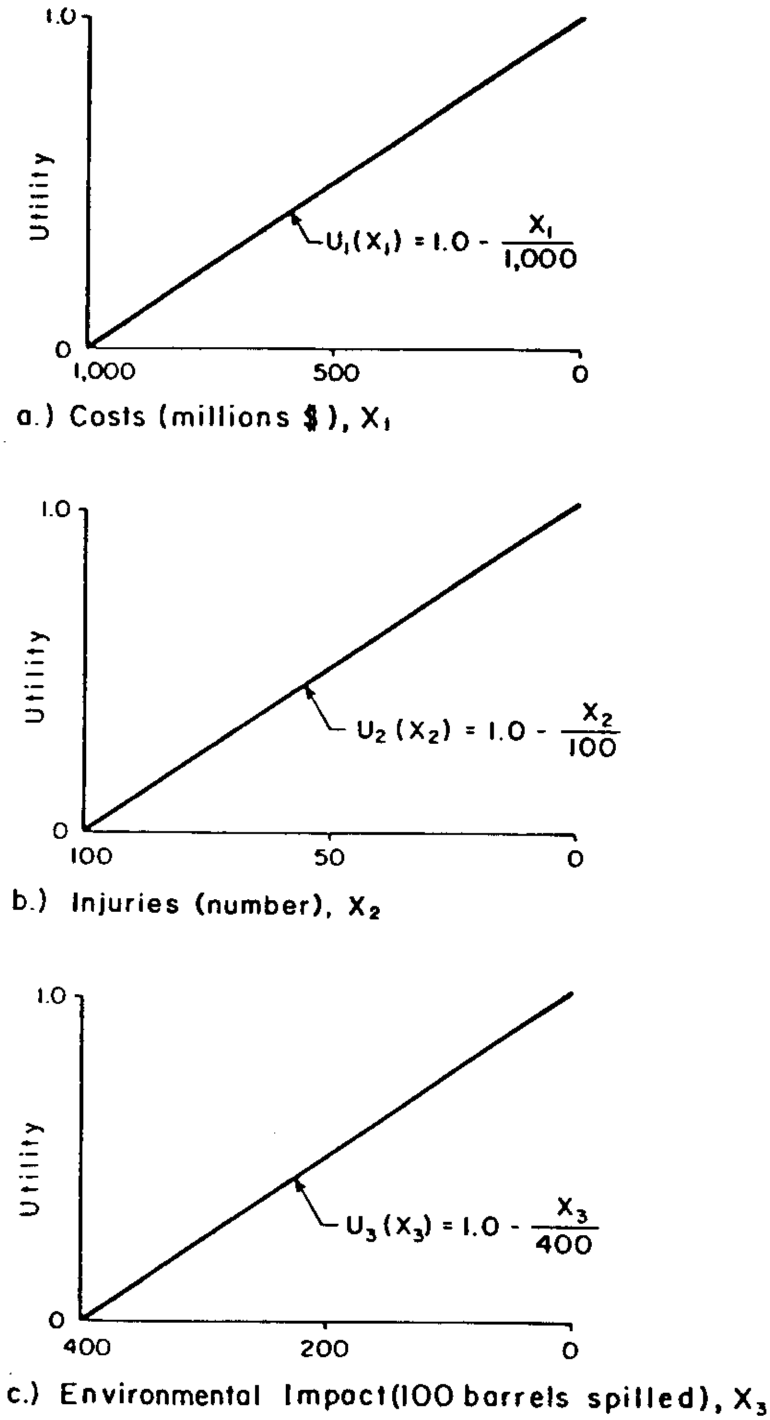


Figure 6-5 Mining Accident Rates versus Wage Incentives

UTILITY VALUATION



$$U = \frac{K_1}{\Sigma K} U_1 + \frac{K_2}{\Sigma K} U_2 + \frac{K_3}{\Sigma K} U_3$$

Figure 6-6 **Utility Based Valuation of Potential Negative Impacts Represented by Dollars, Injuries, and Barrels of Oil Spilled**

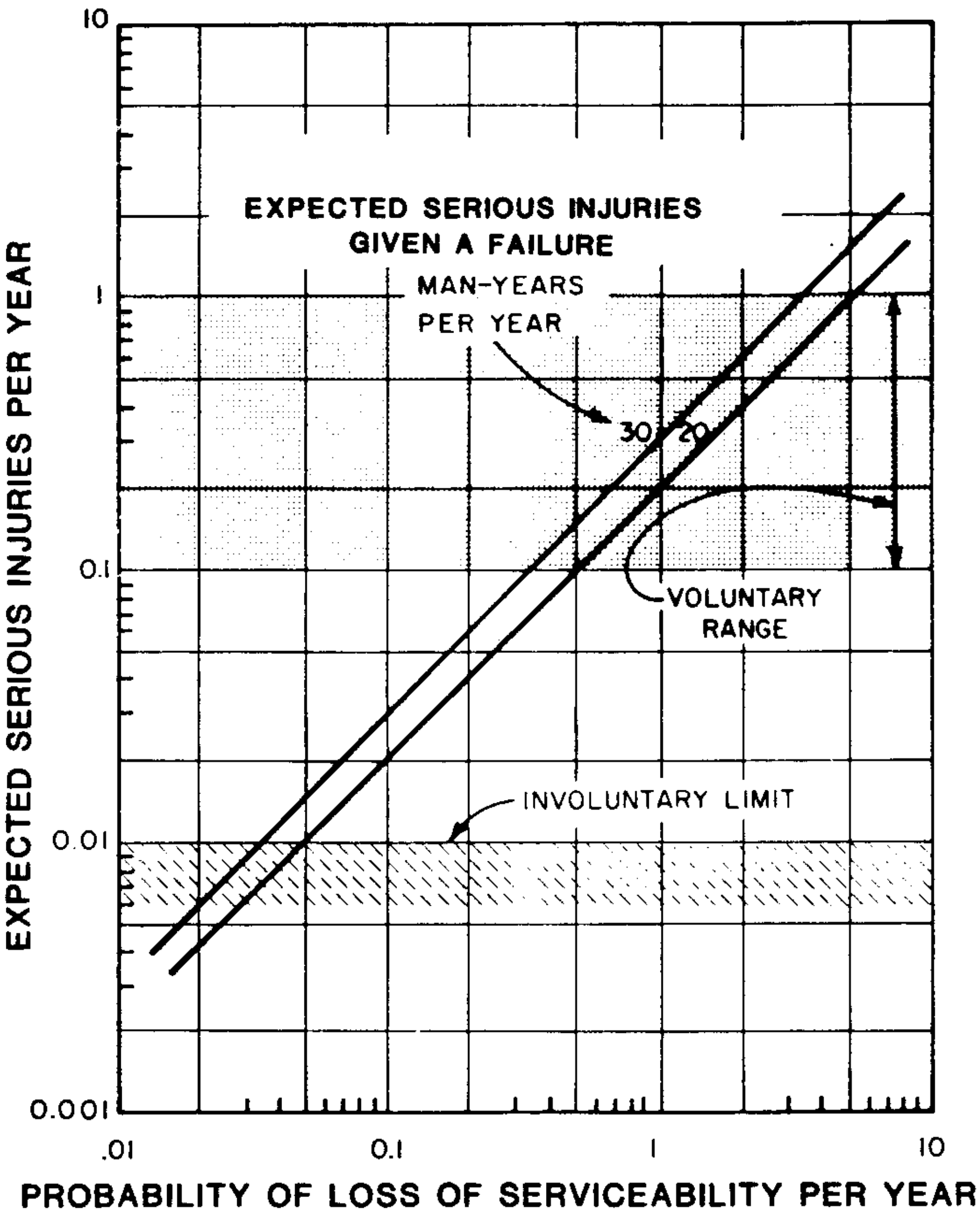


Figure 6-7 **Valuation of Risks of Serious Injury Based on Historic Voluntary and Involuntary Activity Ranges (Figure 6-3)**

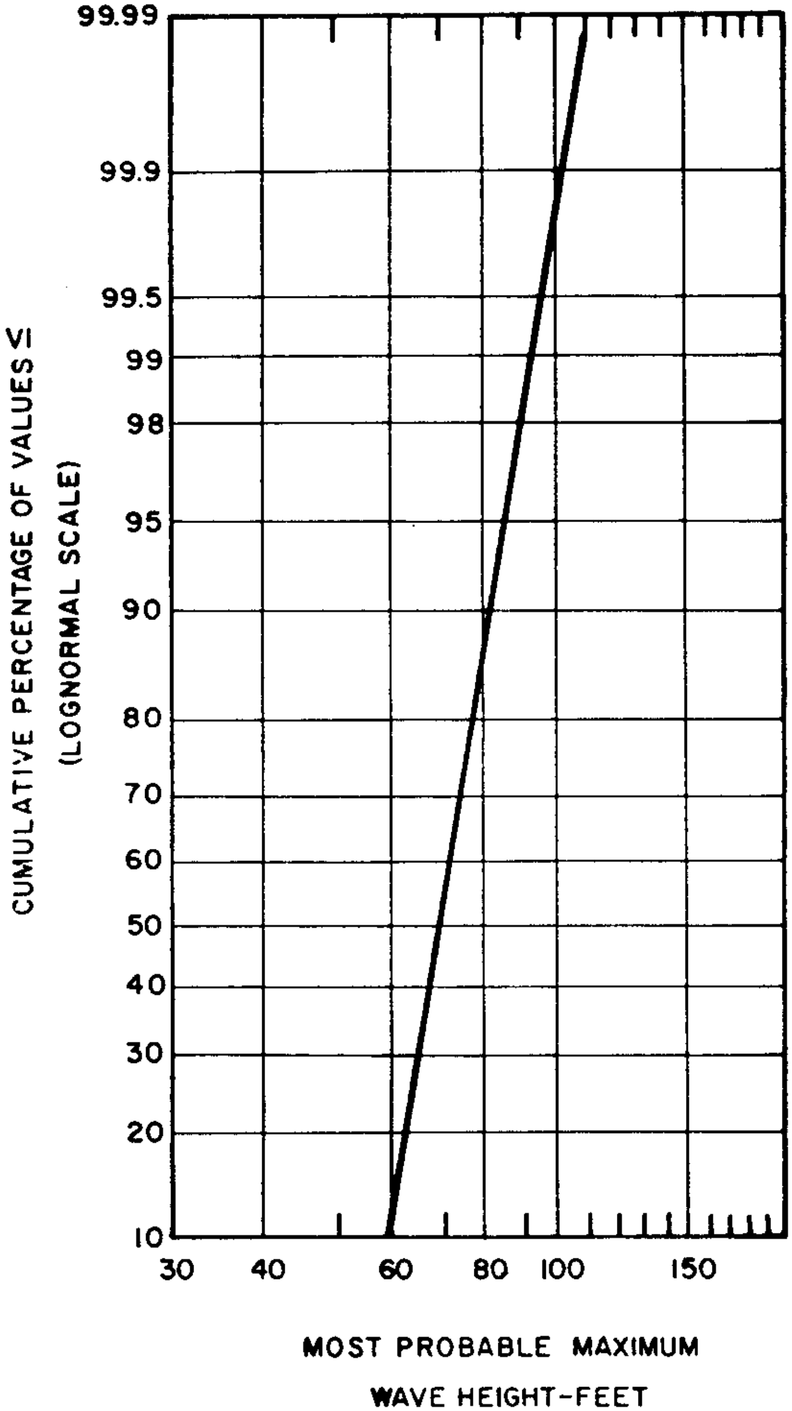


Figure 6-8 **Example North Sea Platform Expected Annual Maximum Wave Heights and Likelihoods of Occurrence**

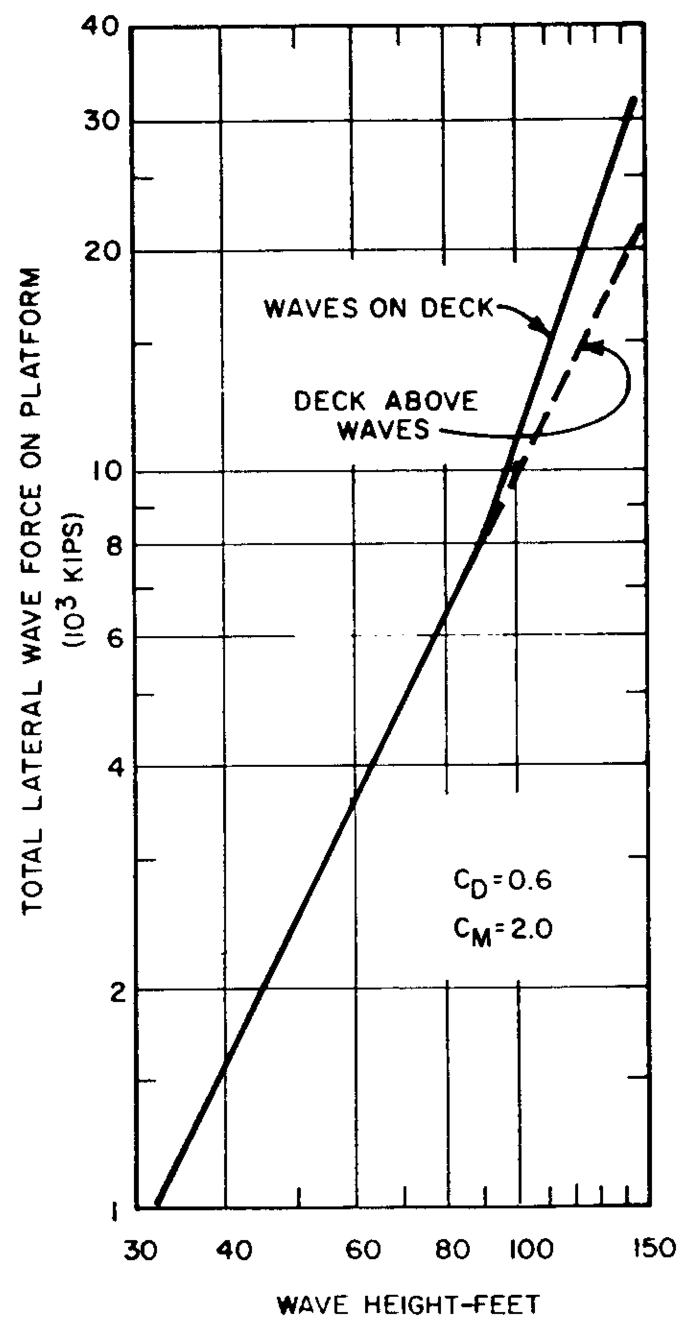


Figure 6-9 Computed Wind, Wave, and Current Forces Acting on Example North Sea Platform

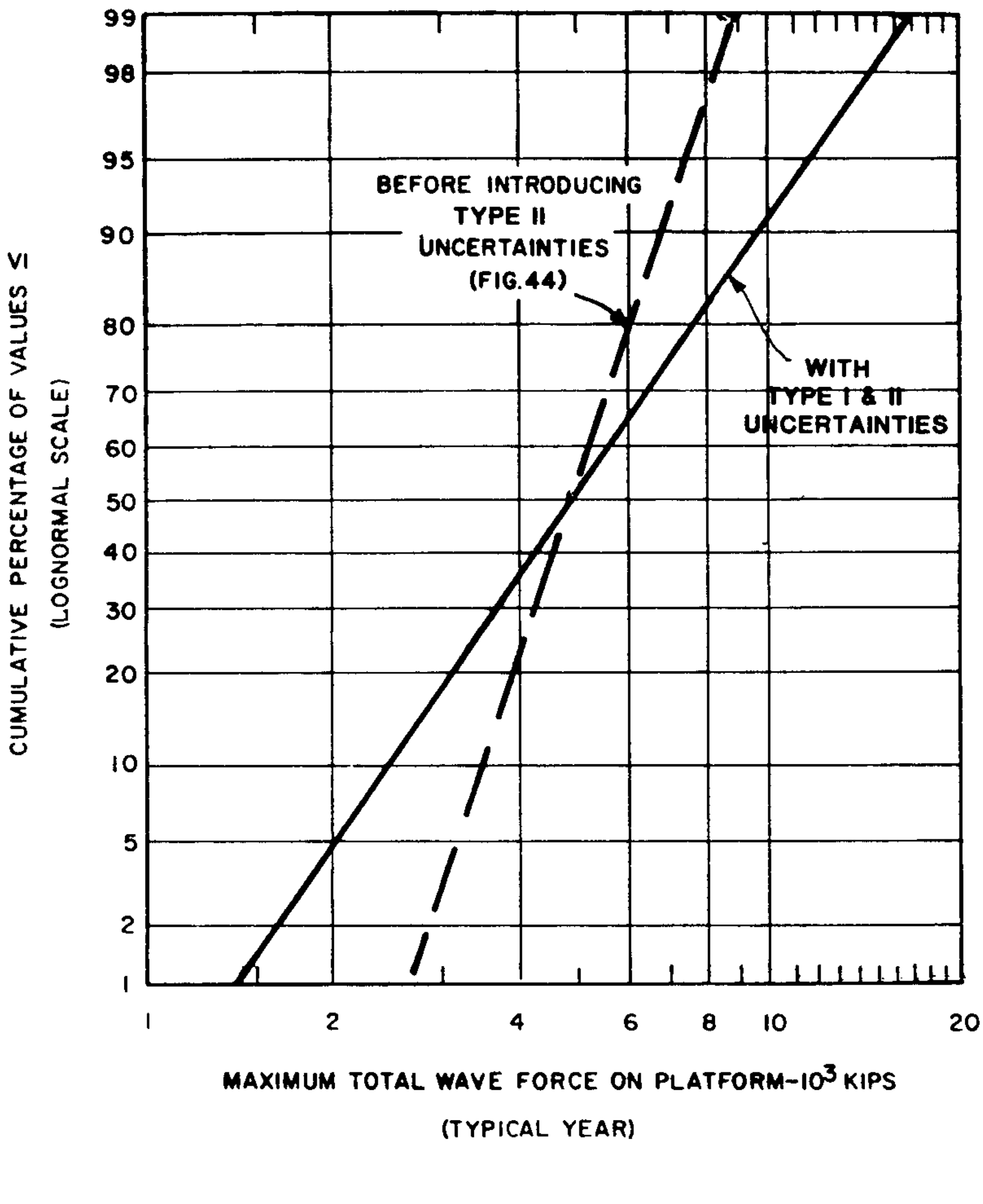


Figure 6-10 **Type I Uncertainties (Natural, Inherent) and Type II Uncertainties (Analysis, Modeling) Influence on Platform Loading Distributions**

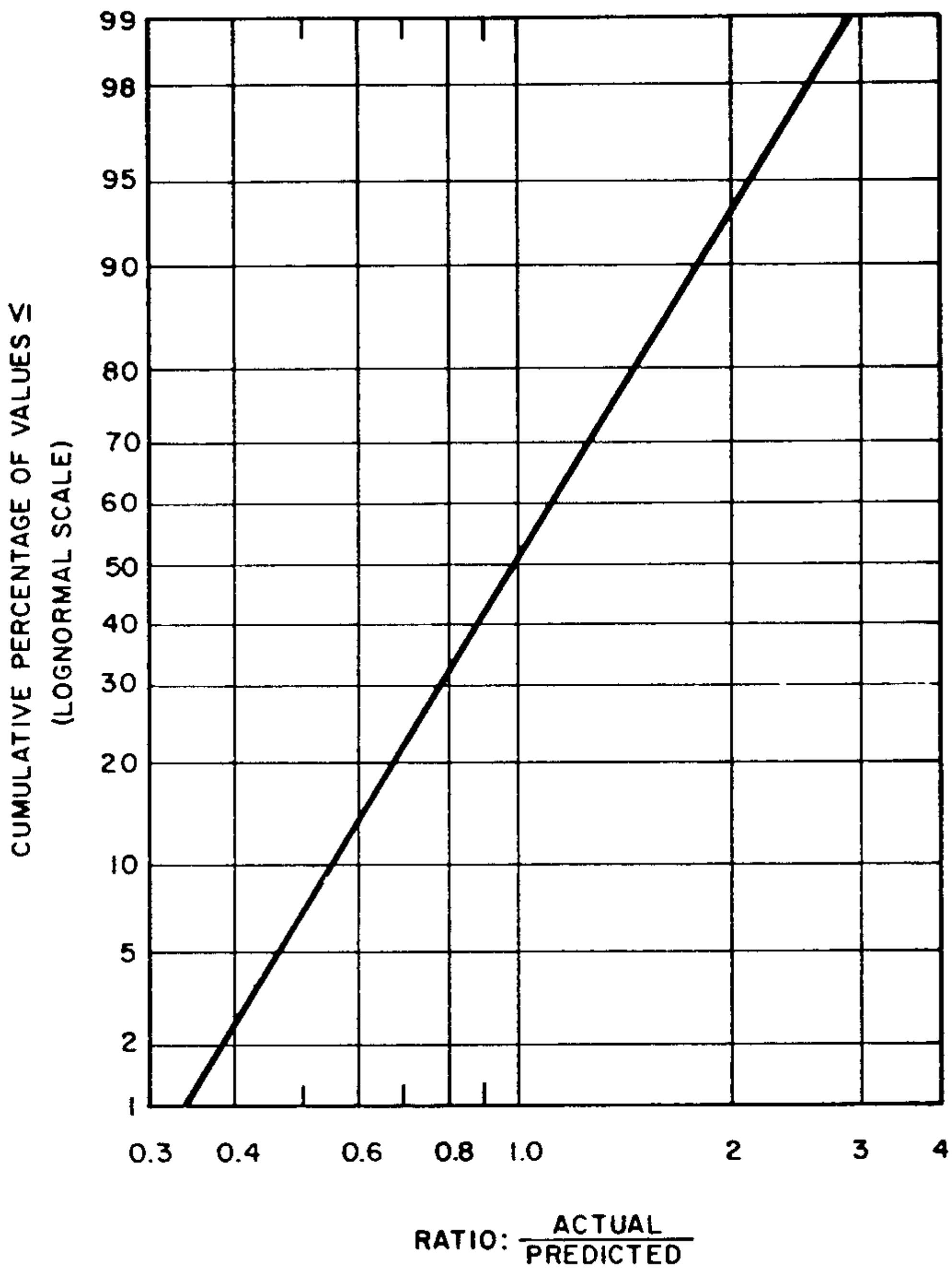


Figure 6-11 Assessment of Uncertainties in Predicted (Computed) Wave and Current Forces

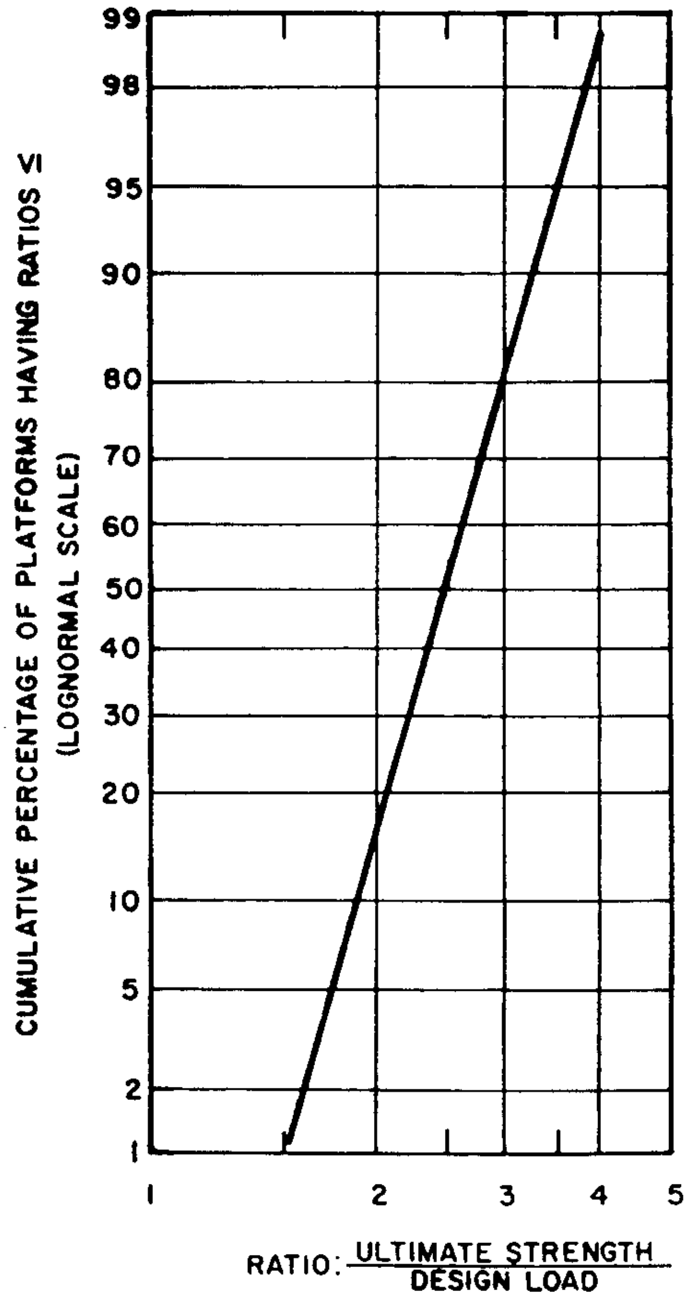


Figure 6-12 **Example North Sea Platform Strength and RSR Distribution**

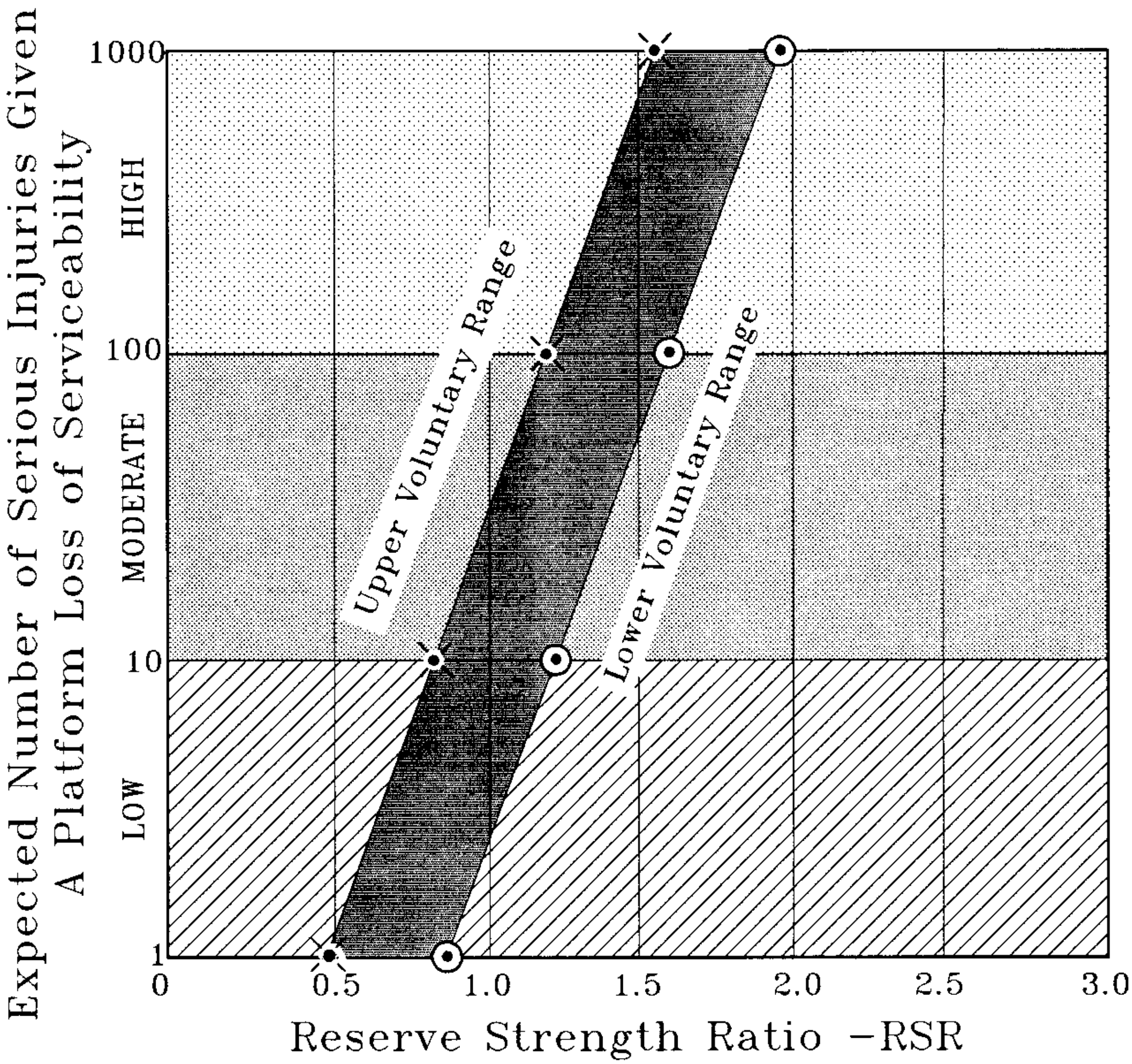


Figure 6-13 RSR versus Expected Number of Serious Injuries Given a Platform Loss of Serviceability Based on Historic Activity Voluntary and Involuntary Risk Rates (Figure 6-7)

AJM 03B345
FL/DISK.001
/AJM/CHRTS
FIG-e.DRW

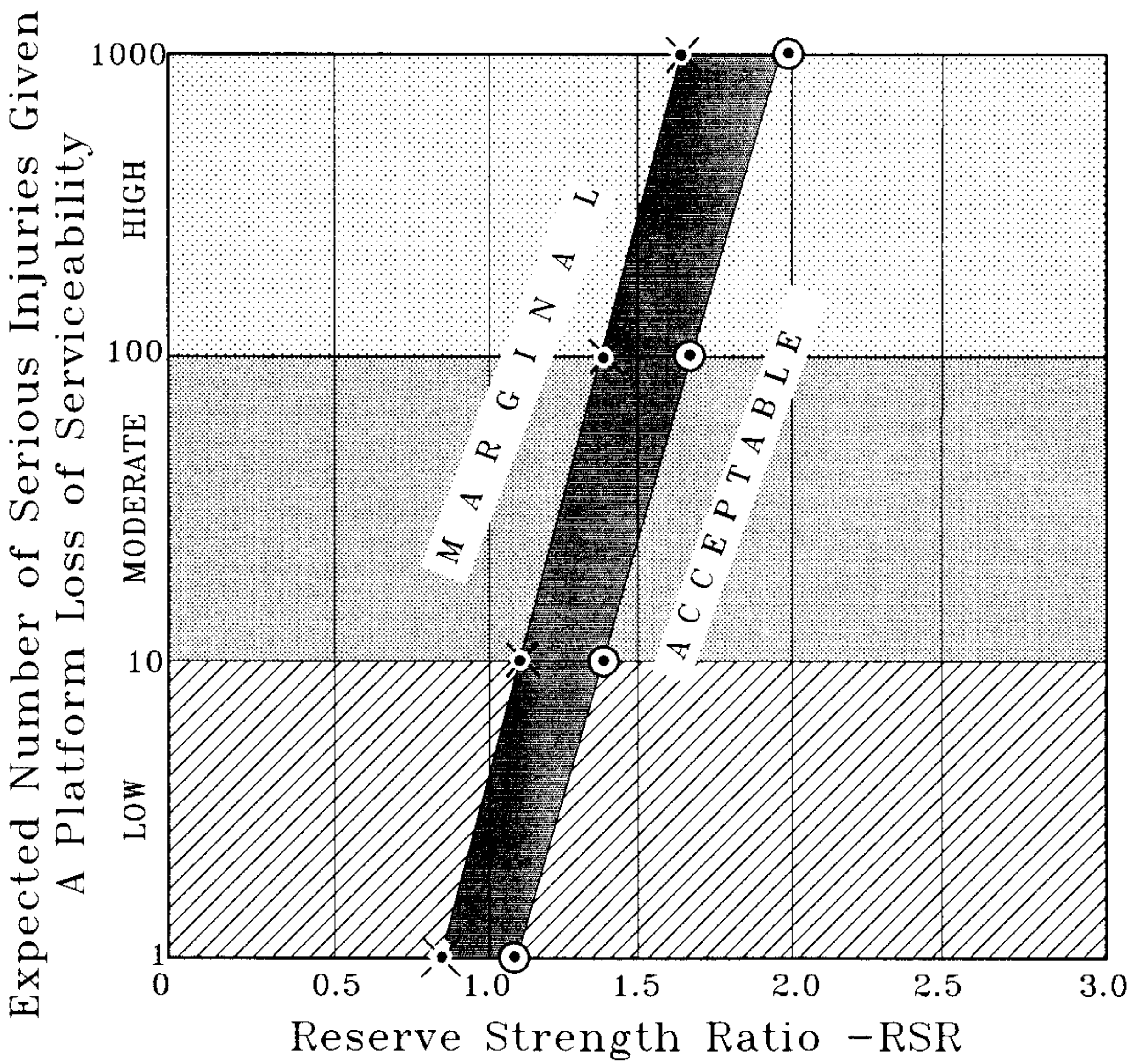


Figure 6-14 **RSR versus Expected Number of Serious Injuries Given a Platform Loss of Serviceability Based on Historic Marginal and Acceptable Serious Injury Risks (Figure 1-2)**

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FIG-F.DRW

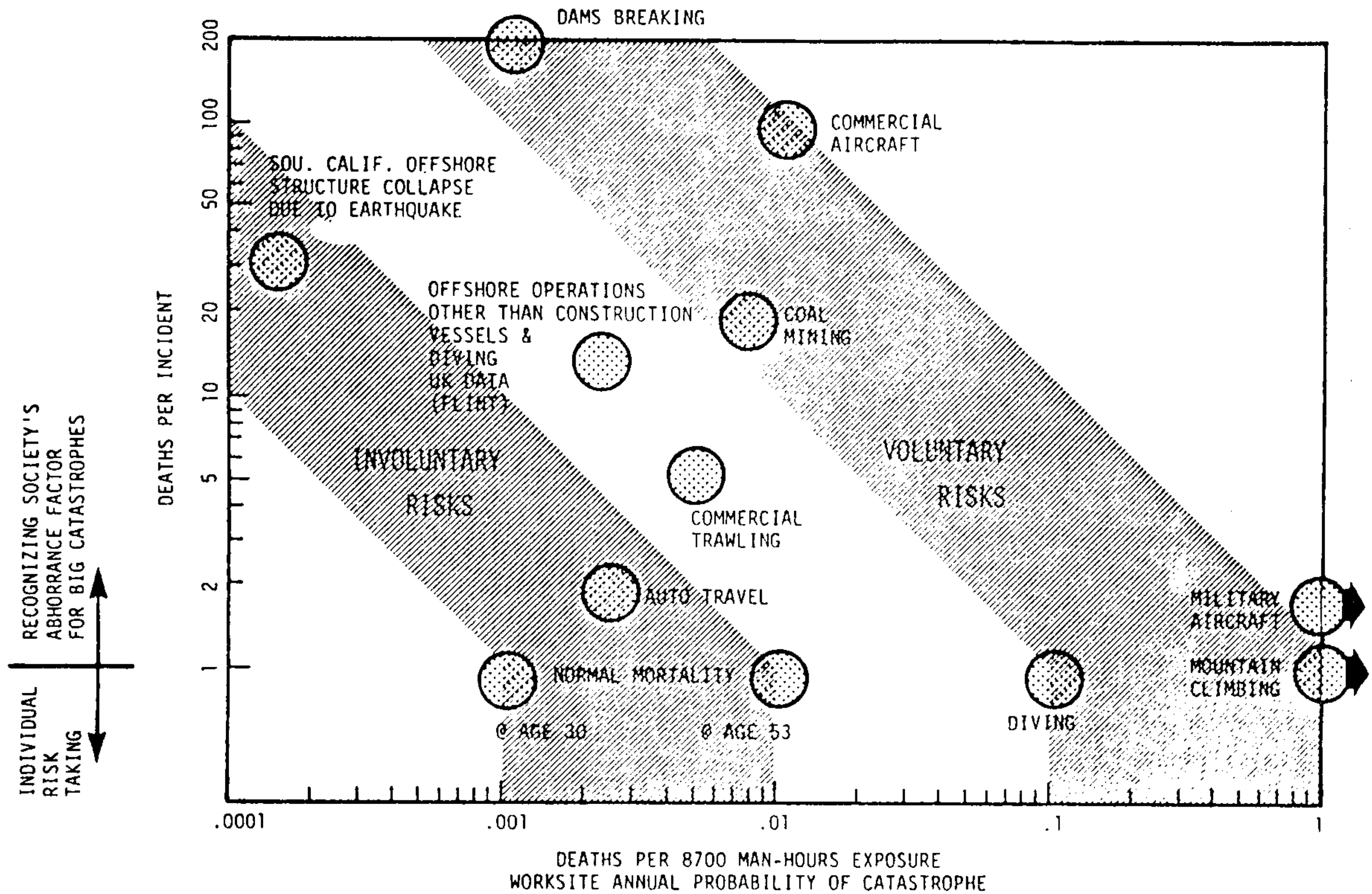
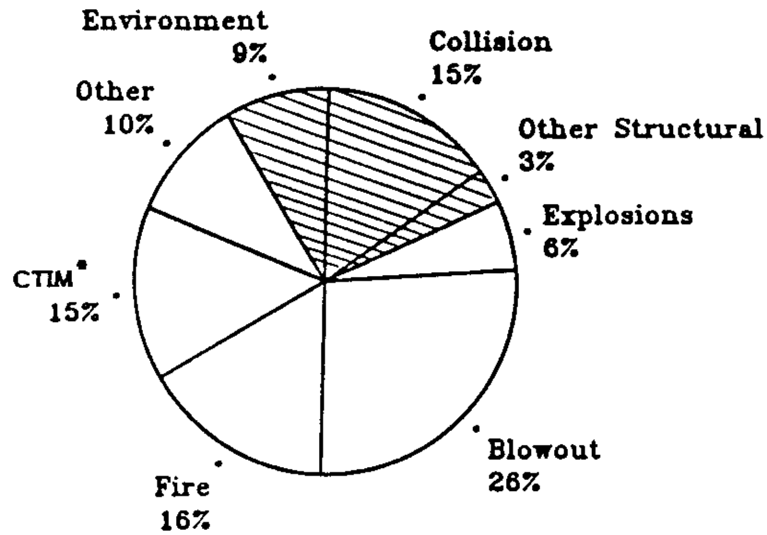


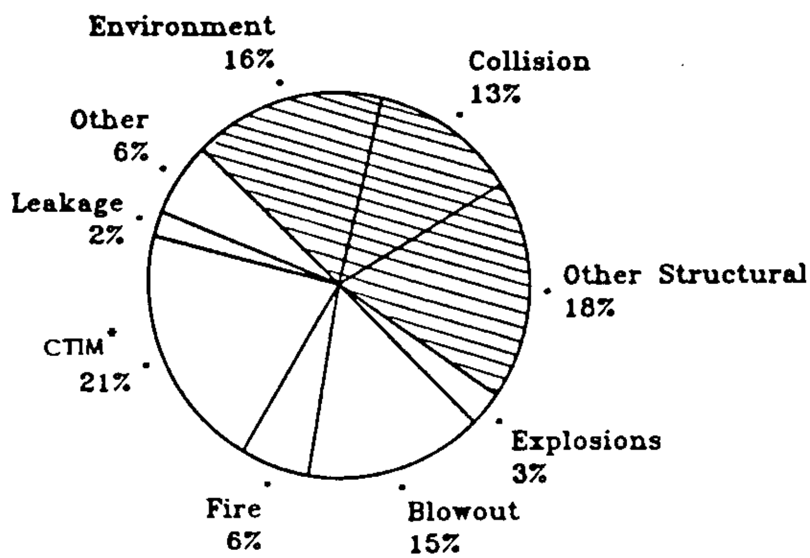
Figure 6-15 **Voluntary and Involuntary Serious Injury Risks Based on Historic Data and Subjective Evaluations of Ranges (Figure 6-3)**

Severe Accidents - Fixed Structures
Worldwide,excluding JU s- 1970-84



(a)

Severe Accidents - Jack-Up Structures
Worldwide- 1970-83



CTIM: Construction, Transportation, Installation and Mobilization

(b)

Figure 6-16 Offshore Platform Accidents by Causes (Table 6.1)

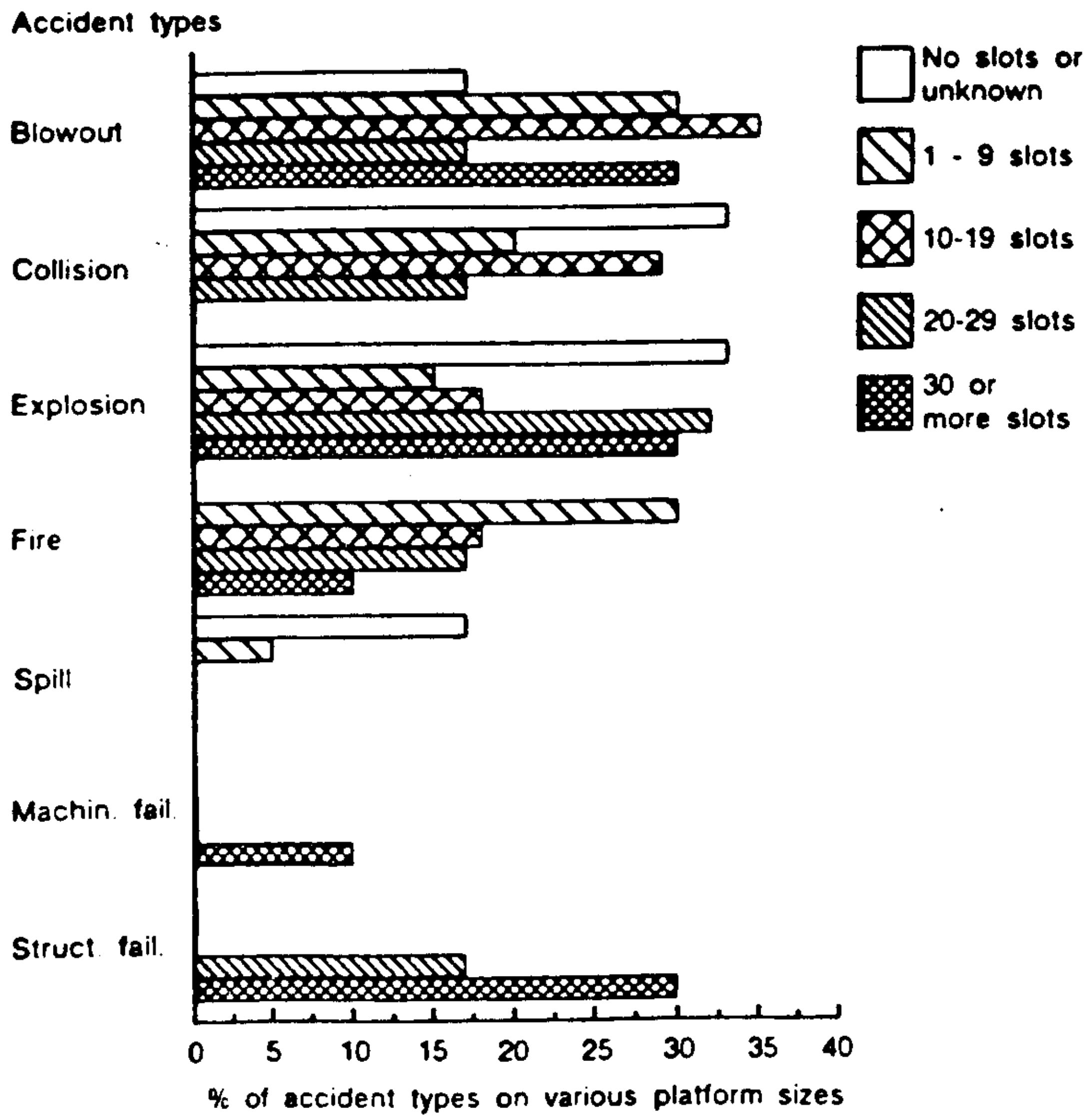


Figure 6-17 **Number of Platform Wells Related to Rates of Serious Accidents on Fixed Offshore Platforms in North Sea and Gulf of Mexico**

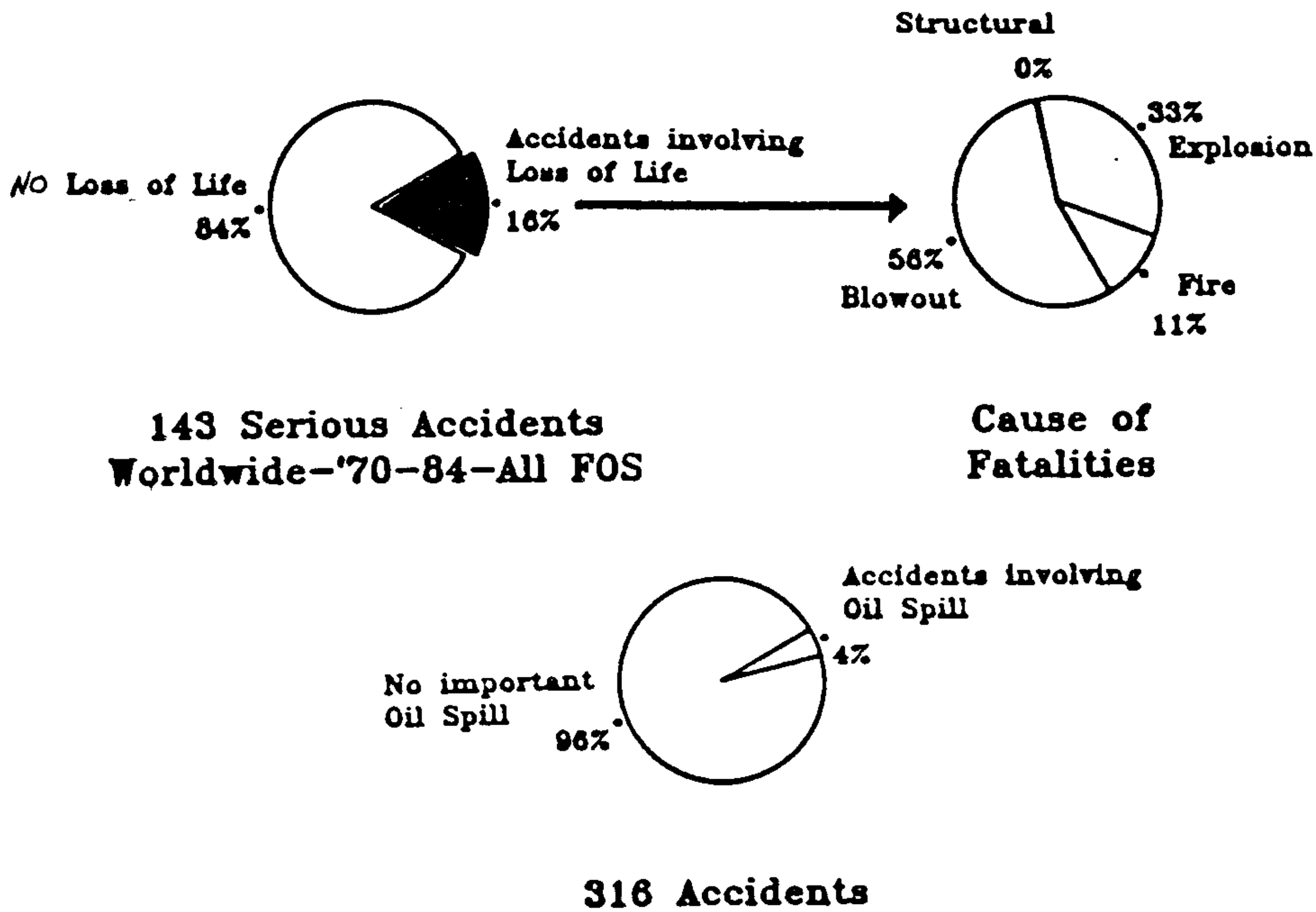


Figure 6-18 Consequences of Accidents on Fixed Offshore Platforms 1970-1984

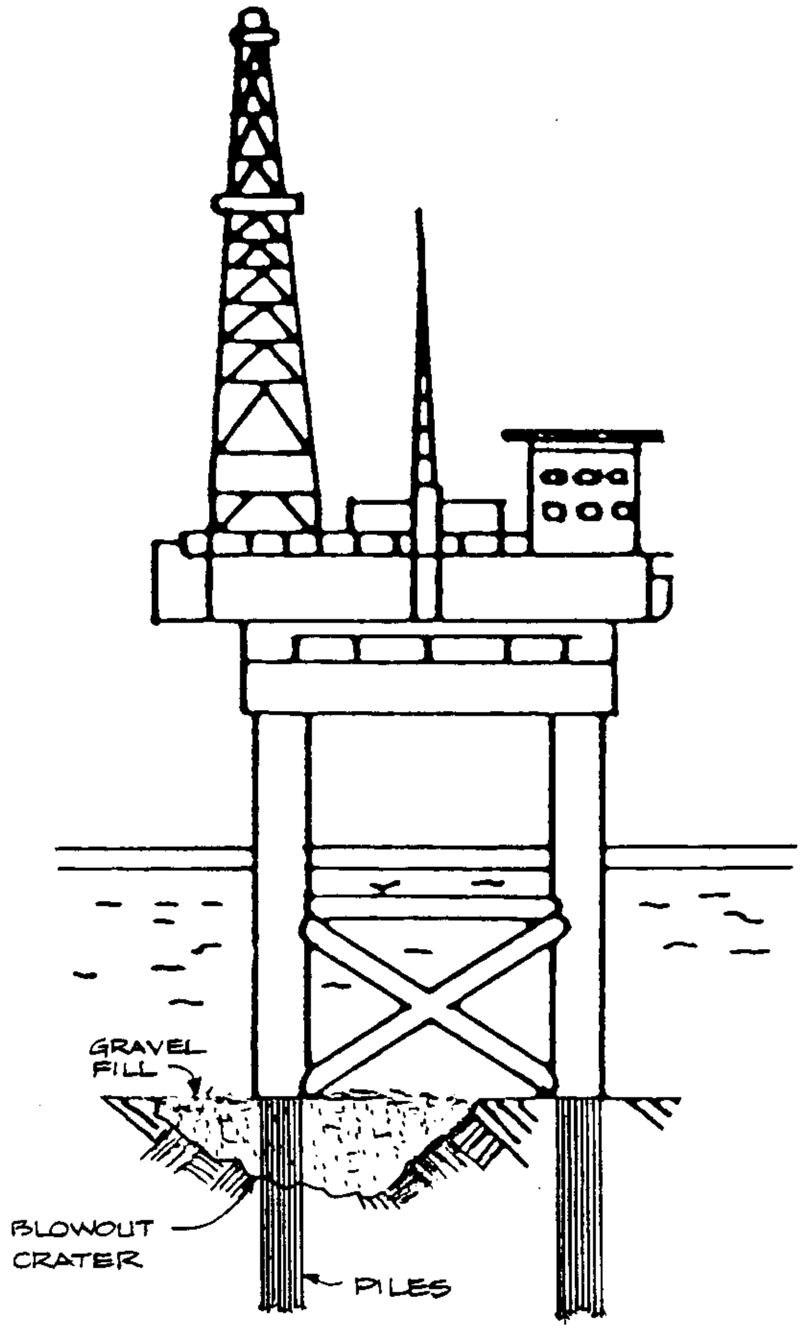


Figure 6-19 Example High Consequence Platform in Cook Inlet, Alaska

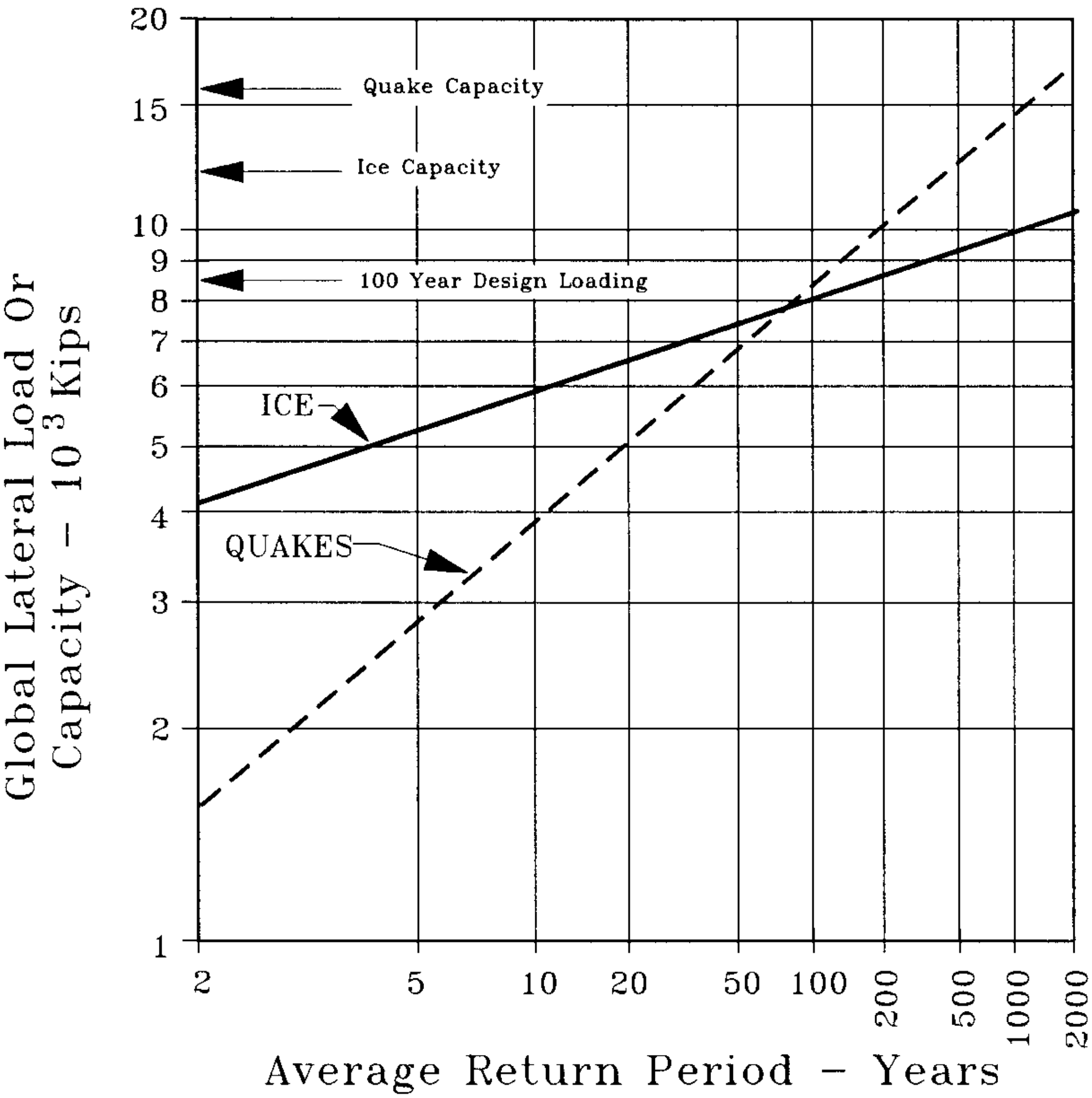


Figure 6-20 Return Periods of Total Expected Maximum Lateral Ice and Earthquake Loadings

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FIG-C.DRW

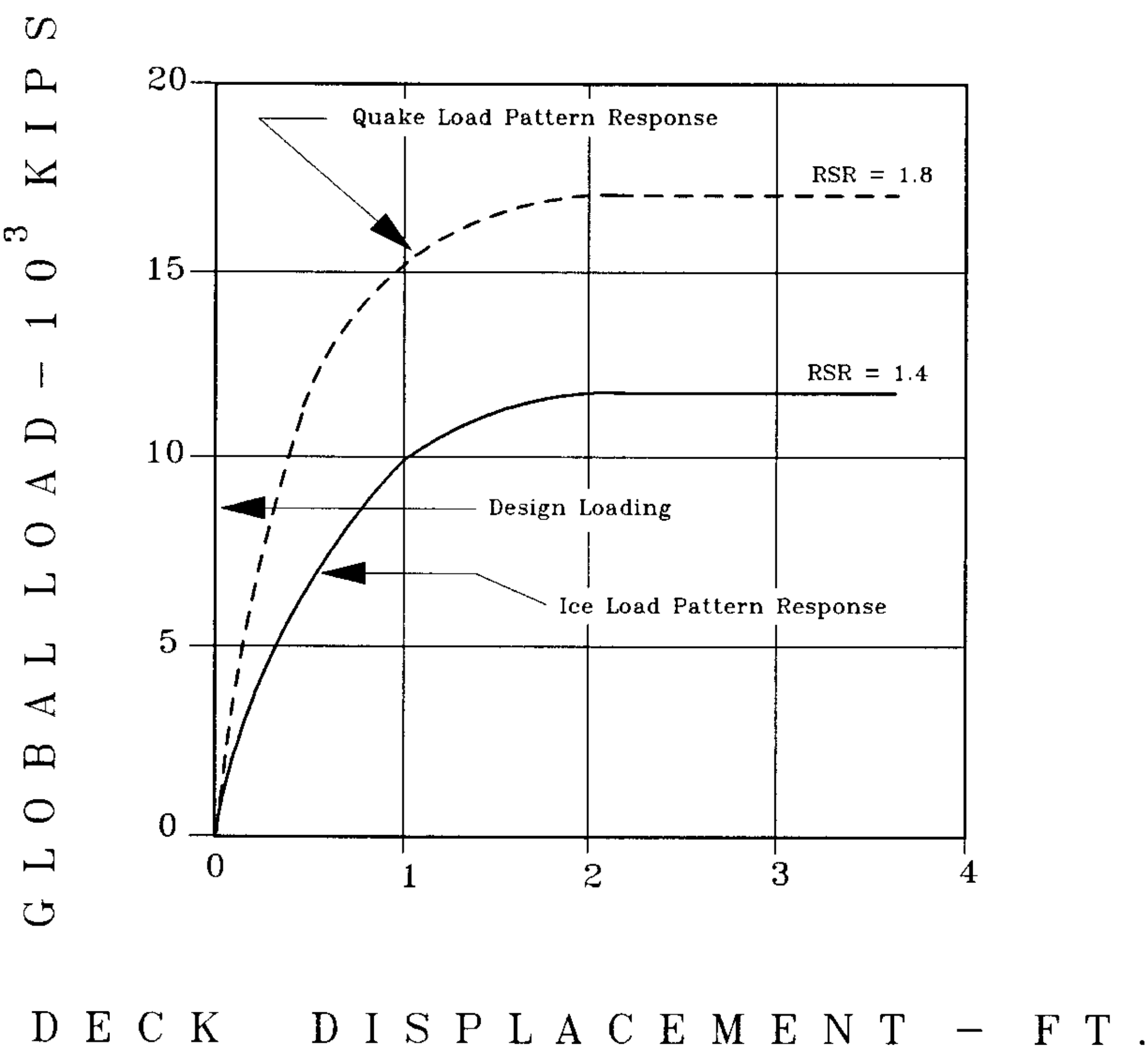

Figure 6-21 Static Push-Over RSR Analysis of Example Cook Inlet Platform

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/AIM/CHRTS
FIG-G.DRW

7.0 CONCLUSIONS

This report has addressed the development of guidelines for evaluations and justifications of suitability for service. The development has been illustrated with results from platform AIM requalification experiences.

The guidelines have been based on the AIM-SS (Suitability for Service) Format. This format relates a measure of the platform capacity or strength to three categories of potential consequences (Figure 3-1).

The measure of the platform capacity or strength is the Reserve Strength Ratio, RSR (Figure 3-2). The RSR is the ratio of the Ultimate Limit State (platform rendered unserviceable) capacity of the structure, R_c, to a reference force, F_r. The platform capacity is determined from static, nonlinear, push-over analyses. The reference force is determined from current guidelines that define the minimum prudent level of loadings that a new platform should be designed to resist.

The measure of the platform potential consequences is expressed through three general categories. A Low Consequence category (Category 1) would be a platform and its AIM program that would pose no or little risks to the environment, resource, life, or property. A High Consequence category (Category 3) would be a platform and its AIM program that would pose significant or major risks to the environment, resource, life, or property. A Moderate Consequence category (Category 2) would be a platform and its AIM program that would pose hazards to the environment, resource, life, or property that are between Categories 1 and 3.

An analytical framework (AIM-SS) has been developed to relate the RSR to measures of potential consequences (Section 4). This framework will allow one to account for inherent and engineering uncertainties, desired levels of safety, and the likelihood of future extreme loading events acting on platforms.

Several approaches have been developed and explored to provide quantifications for the AIM-SS analytical framework. These include historic (what has been accepted in the past), calibration (what is being accepted at the present), and utility (what represents a highest utility option) approaches.

Actuarial data on performance of Gulf of Mexico platforms, and information from recent Gulf of Mexico AIM platform requalifications have been used to illustrate these approaches as they can be used to relate RSR's to Low and Moderate Consequence platforms. In addition, a cost-benefit approach has been formulated and explored to indicate how such an approach might be used to evaluate platform suitability for service.

Example results from these approaches for Gulf of Mexico operations are summarized in Figure 7-1. Monetary characterizations of the consequences categories could be taken as $1 millions to $10 millions (Category 1), $10 millions to $100 millions (Category 2), and $100 millions to $1,000 millions (Category 3).

Because of their potentially unique aspects, evaluations of manned platforms have been addressed (Section 6). Several approaches have been developed and explored to provide quantifications for the AIM-SS framework.

These include economic, utility, and experience based valuations. Results from two high consequence platforms have been used to illustrate applications of these approaches (North Sea platform and Cook Inlet platform).

Example results from these approaches for manned platforms are summarized in Figure 7-2. The consequences scale of potential severe injuries could be related to three general categories. Category 1 could relate to 1 to 10 potential severe injuries; Category 2 could relate to 10 to 100 potential severe injuries; and Category 3 could relate more than 100 potential severe injuries.

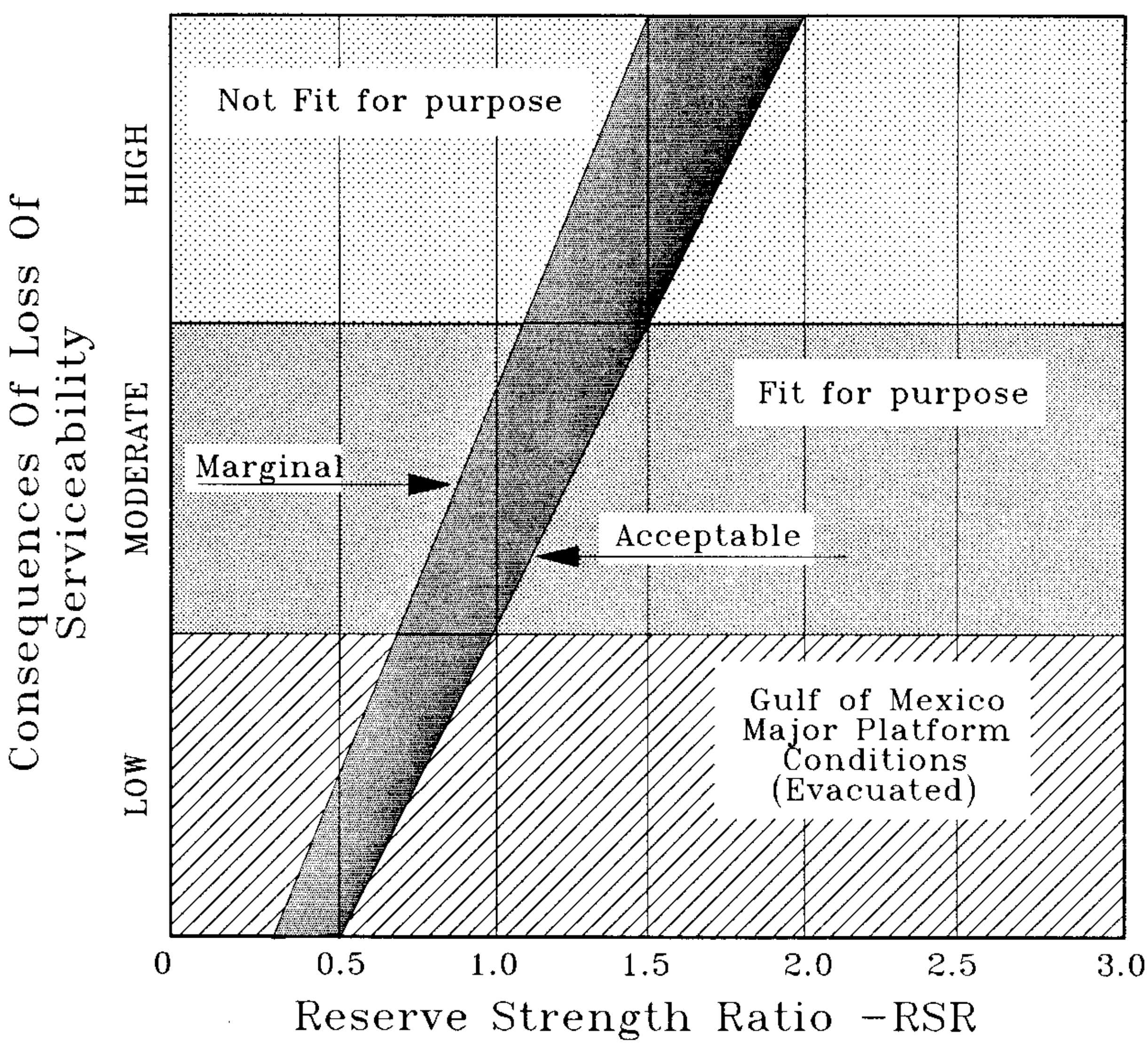

Figure 7-1 **AIM-Suitability for Service Evaluations for Gulf of Mexico Platforms (Evacuated in Advance of Severe Hurricanes)**

AIM 038345
FL/DISK.001
/AIM/CHRTS
FIG-A.DRW

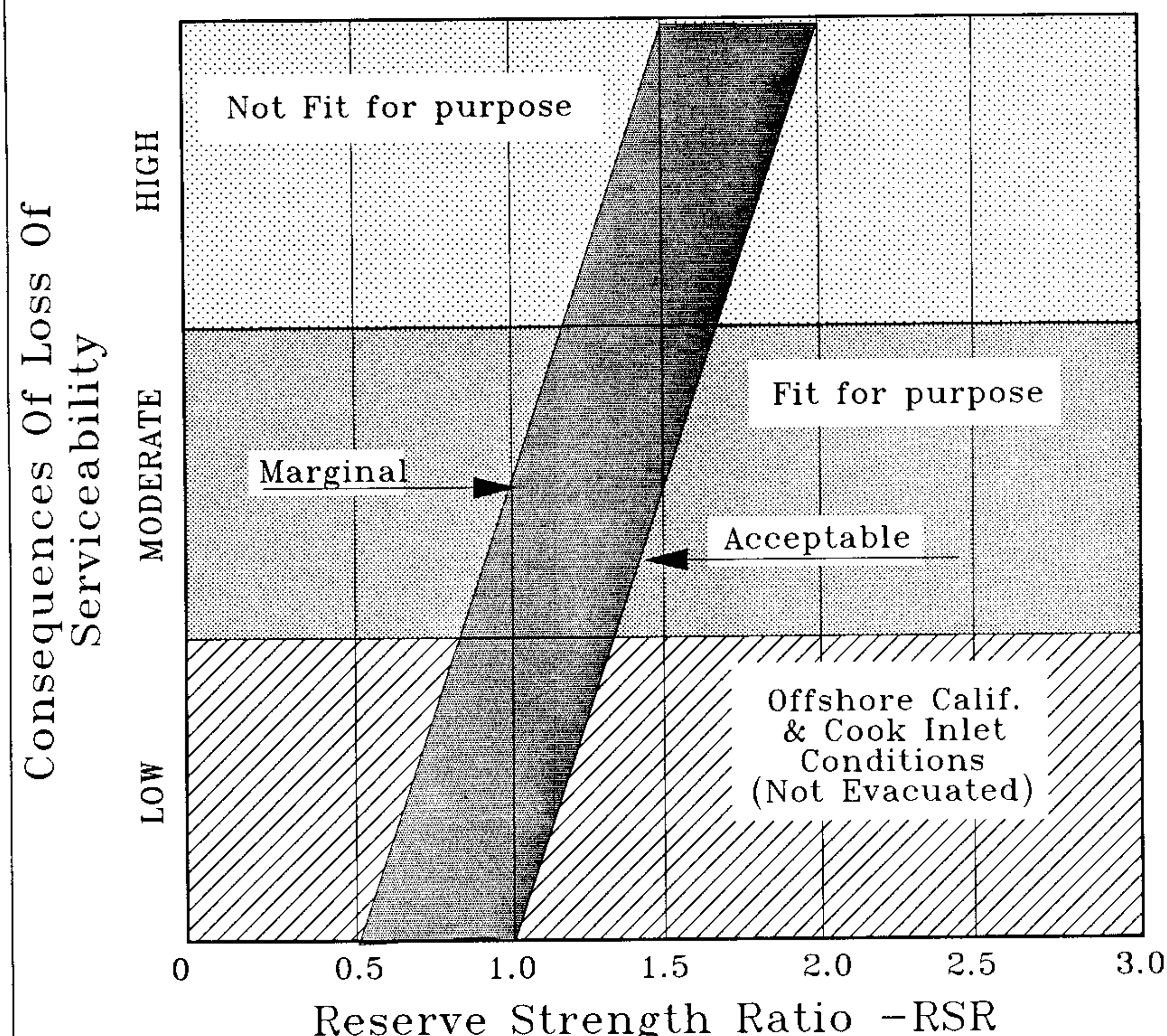

Figure 7-2 AIM-Suitability for Service Evaluations for High Consequence (Not Evacuated) Platforms

AIM 038345
FL/DISK.001
/AIM/CHRTS
FIG-b.DRW

8.0 IMPLEMENTATION

This report has developed a format for evaluations and justifications of AIM program and platform suitability for service; the AIM-SS format. The particular focus of this format is that of the public-regulatory domain.

Further, an analytical framework has been provided to assist in making judgements concerning AIM program and platform suitability for service. Considerations are given to property, resource, environment and life-safety issues.

The next issues regard how to implement such a development. In the remainder of this section, we will outline how implementation might proceed.

The Committee on Offshore Energy Technology of the Marine Board Assembly of Engineering, National Research Council has addressed this issue [33]. In the section of this report titled "Inspection Management," the committee addresses an organization of functions and responsibilities appropriate for AIM requalification planning (Figure 8-1).

The organization is very similar to the present offshore platform verification process for new structures. Details of the implementation plan are outlined in the section of the report titled "Implementation".

There are two key documents that are referenced in this organization that do not exist at the present time. The first is platform requalification engineering guidelines. The second is AIM program and platform performance and evaluation standards.

Platform requalification engineering guidelines (how to do it) could be similar to the current Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms [4]. These guidelines could be based on the AIM developments and comparable efforts taking place in other offshore communities. Due to the need for the guidelines to represent an industry/government development, such an effort could be undertaken by the American Petroleum Institute. The guidelines could then be reviewed, revised, and approved by the Minerals Management Service.

Similarly, AIM program and platform performance and evaluation standards need to be developed. Hopefully, this report represents a place to start such a development. Again, such a development needs to represent an industry/government consensus. A group such as the Marine Board could undertake such an effort with industry and government representation. The results could eventually be incorporated into MMS OCS Rules and Regulations [4].

FUNCTION	MANAGEMENT RESPONSIBILITY
Prepare Plan	Industry
Check Plan	USGS/Contractor **
Approve Plan*	USGS
Provide Appeal Route*	USGS
Implement Plan	Approved Inspection Agent
Monitor Implementation	USGS/Contractor
Failure Reporting Analysis*	USGS
Post Inspection and Repair Review*	Review Board***
Audit Implementation*	USGS

* Functions considered to be government responsibilities.

** USGS/Contractor means: USGS personnel undertake part of the function and may use contractors to assist for selected-definable portions, or contractor undertakes entire function.

*** Detached, high-level group, appointed to review post-inspection and repair after major structural failures.

Figure 8-1 Marine Board Recommended Inspection Management Organization

9.0 ACKNOWLEDGEMENTS

This has been a very difficult report to write. The issues are sensitive. Knowledge is limited. The written word fails to communicate perfectly. And, the constraints of simplicity and practicality were severe.

The AIM-SS effort would have fallen far short of its mark without the help of the AIM-III participants. Many participants have made major contributions which the author would like to recognize.

- Charles Smith (MMS) and Jack Spencer (USCG) for their leadership in initiating this effort and effectively communicating public-regulatory considerations.

- Hugh Banon and Jim Lloyd (Exxon) for their direction in development of the AIM-SS format, in checking its development, and in providing a necessary system of checks and balances in this difficult development.

- Jack Hong, Scott Martindale, Bill Krieger, Don Wilson, and Jim Pfeffer (Chevron) for their patient guidance, comments, and experience in difficult requalification programs.

- Bernie Stahl and Gary Imn (Amoco) for their counseling on how to approach quantifications in the AIM-SS format and for debugging the calculations.

- Roger Thomas (Phillips) for his constant reminders of the importance of keeping the AIM process practical and in reaching the operations personnel with a process that can help more than it can hurt.

- Mike Isenhower and Mike Craig (Union) for their substantial input to the AIM process developments in platform screening and difficult requalifications.

- Pat Dunn, Peter Marshall, Peter Arnold, Kris Digre (Shell) for always providing support and assistance in backgrounding and directing the AIM effort.

- Griff Lee and Ben Gerwick, Jr. for their unique abilities to identify and provide insight to solve difficult AIM issues and problems.

- Dan Beal (Arco), Bob Visser (Belmar), Chet Eaton and Martin Eskijian (California State Lands), Bob Ohmart and Ashok Kumar (Conoco), Jim Saunders and Ron Antes (Marathon), Danny Gray and Bob Gair (Hudson), Tom Rees (Oxy), Gene Kuhn and Clair Menning (Mobil), John Baxter and Ken Bitting (USCG) for their leadership in directing the course of this effort.

Particular thanks are expressed to the authors of the written report reviews contained in Appendix A.

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APPENDIX A

DISCUSSIONS

This report was sent out in draft format to the AIM participants and consultants. Their comments and discussions of the draft report are provided in this appendix. Their comments have been included in the final version of the report.

PARTICIPANTS/CONSULTANT COMMENTS

TO AIM III DRAFT REPORT NO. 3

1.	Exxon - Hugh Banon	July 18, 1988
2.	Griff Lee	August 12, 1988
3.	Ben C. Gerwick	August 15, 1988
4.	Oxy USA, Inc. - Tom Rees	August 16, 1988
5.	Chevron - Jack Hong/Scott Martindale	August 22, 1988
6.	United States Coast Guard - Jack Spencer	August 23, 1988
7.	Shell Oil Company - Kris Digre	August 24, 1988

There have also been several verbal comments and suggestions not referenced here. We thank all participants and consultants for their input to the review.

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cc 7JP

PMB SYSTEMS ENGINEERING, INC. RGG
DKD

JUL 19 1988

RECEIVED

EXXON PRODUCTION RESEARCH COMPANY
POST OFFICE BOX 2189 • HOUSTON, TEXAS 77252-2189

OFFSHORE DIVISION

J. F. WOLFE
MANAGER

July 18, 1988

Mr. Frank Puskar
PMB Systems Engineering
500 Sansome St.
San Francisco, CA 94111

Dear Mr. Puskar:

AIM (Phase III) Joint Industry Project

Attached please find our review comments regarding Phase III of the AIM Joint Industry Project. We understand that you will distribute these comments to the project participants. If you agree with our comments, the required modifications to the AIM report should be relatively easy to implement. We also suggest that the participants be given an opportunity to review the Phase III report before it is finalized.

Overall, we believe that the project has been a success, i.e., PMB has convinced the participants of the usefulness of the reserve strength approach in requalification of early generation platforms. The AIM study has also helped to better understand the challenging problems in requalification and fitness-for-purpose of offshore platforms.

Any questions regarding the attached comments should be directed to Hugh Banon at (713) 940-4608.

Very truly yours,

J. F. Wolfe

By P. G. Titus
P. G. Titus

HB:ls

c: C. R. Brinkmann
J. R. Lloyd

File: 3783

AIM Phase III Comments

The following comments pertain to the development of guidelines for evaluations and justifications of suitability for service. In our July 7-8 meeting, I pointed out that some of the RSR values calculated seemed to be very low considering the postulated consequences of failure. For example, in the attached Figure 19 of the meeting handout, an RSR of less than 1.0 is shown to be satisfactory for consequences of failure up to \$100 M. I believe that the following observations and suggested changes would resolve the discrepancies in the PMB calculations.

As presented by Bob Bea, the platform RSR can be written as:

$$RSR = FR \exp(-\beta U) \tag{1}$$

where FR is the ratio of the annual median (50 percentile) load to the 100-year design load, β is the annual target safety index, and U is the logarithmic standard deviation (assuming Lognormal distributions for both the load and resistance) representing the overall variability in the failure. In the above equation, U includes: 1) the variability in the wave height, 2) the uncertainty in the wave load modeling, 3) the uncertainty in the platform resistance, and 4) the uncertainty in our platform resistance models. As pointed out by Bob Bea, assuming U to be in the range of 0.6-0.8 and the annual target safety index to be in the range of 2.5-3.5 is reasonable.

The ratio FR can be calculated assuming that the platform load can be obtained from the following parametric equation:

$$L = c\ H^{\alpha} \tag{2}$$

where α is approximately 2 for a drag dominated structure (Our recent API research supports using an exponent α which is a function of the water depth). In order to model the uncertainty in the above equation, one can add another term to the equation as follows:

$$L = e * (c\ H^{\alpha}) \tag{3}$$

where e models the uncertainty in our calculation of the load (e.g., the drag coefficient, etc.); e is a Lognormal random variable with median equal to 1.0 and logarithmic standard deviation equal to σ_e. Assuming that the wave height H has a Lognormal distribution with logarithmic standard deviation σ_h, the total uncertainty in L is:

$$\sigma_L = \sqrt{(\alpha\sigma_h)^2 + \sigma_e^2} \tag{4}$$

Therefore, the ratio FR can be written as:

$$FR = \exp[-2.33\ \sqrt{(\alpha\sigma_h)^2 + \sigma_e^2}] = \exp[-2.33\sigma_L] \tag{5}$$

Notice that the uncertainty term σ_e was left out of the PMB equation. This uncertainty was correctly accounted for in the calculation of U. I suspect that this uncertainty was also left out when platforms A, B, and C were used as examples for calibration of RSR.

An important point to note here is that U is the total uncertainty in the failure event and, therefore, it includes the variability in the load (σ_L) as well as the variability in the resistance (σ_R). In fact, U can be written as

$$U = \sqrt{\sigma_L{}^2 + \sigma_R{}^2} \tag{6}$$

where σ_R represents the variability in the resistance. Substituting Equations 5 and 6 into Equation 1, one obtains:

$$RSR = \exp[-2.33\ \sigma_L].\exp[-\beta\sqrt{\sigma_L{}^2 + \sigma_R{}^2}] \tag{7}$$

We can now show that the combinations of U=0.6-0.8 and FR=0.1 in the attached Figure 19 are not permissible. Setting FR=0.1 in Equation 5 would lead to σ_L=1.0 which is greater than U=0.6-0.8, the total variability in the platform failure (see Eq. 6). Assuming U=σ_L=0.6 (i.e., no variability in the resistance), the minimum value of FR permissible in the attached figure is approximately 0.25. For U=σ_L=0.8, the minimum permissible value of FR is around 0.16.

If the RSR calculations are corrected according to the aforementioned observations, more reasonable results will be obtained. For example, the following is a list of RSR values for the range of target safety index 1.0-3.0 assuming σ_L=0.56 and σ_R=0.30 (typical Gulf of Mexico values) obtained from Eq. 7:

β = 1.0	RSR = 0.51
β = 2.0	RSR = 0.95
β = 2.5	RSR = 1.3
β = 3.0	RSR = 1.8
β = 3.5	RSR = 2.5

My second comment is regarding the RSR calibration process using specific platform models such as platforms A, B, and C. In the PMB calculations, the 100-year and median annual loads were obtained directly from the load VS return period plots such as the attached Figure 22 and then FR was calculated to be simply the ratio of the two loads. This method introduces an unnecessary error because the load probability distribution is not Lognormal and the FR ratio is sensitive to the two values which are read off the curve. A better method of calculating FR is to fit a parametric equation such as Eq. 2 to the load curve (e.g., Figure 22). Next, the ratio FR can be calculated according to the above procedure taking into account the variability in wave height and the uncertainty in our load models. By fitting a nonlinear equation to the load curve using a regression technique, one in effect assures that the best-fit distribution for <u>all</u> load values is used and the errors are minimized. Although this method is more cumbersome, the results will not be sensitive to the values of 100-year and median loads as in the PMB procedure.

In the above discussion, I have used σ (consistent with the PMB notation) to denote a logarithmic standard deviation assuming all distributions are Lognormal. However, you may want to use a different notation, because σ is usually used to denote a simple standard deviation and not the logarithmic standard deviation. I am concerned about mistakenly using standard deviations in the above procedure. Also the user should be cautioned that a logarithmic standard deviation deviates very rapidly from the coefficient of variation as the probability distribution becomes wider.

H. Banon

PROJECT ________ PAGE ________
BY ________ DATE ________
PMB SYSTEMS ENGINEERING, INC.
SAN FRANCISCO

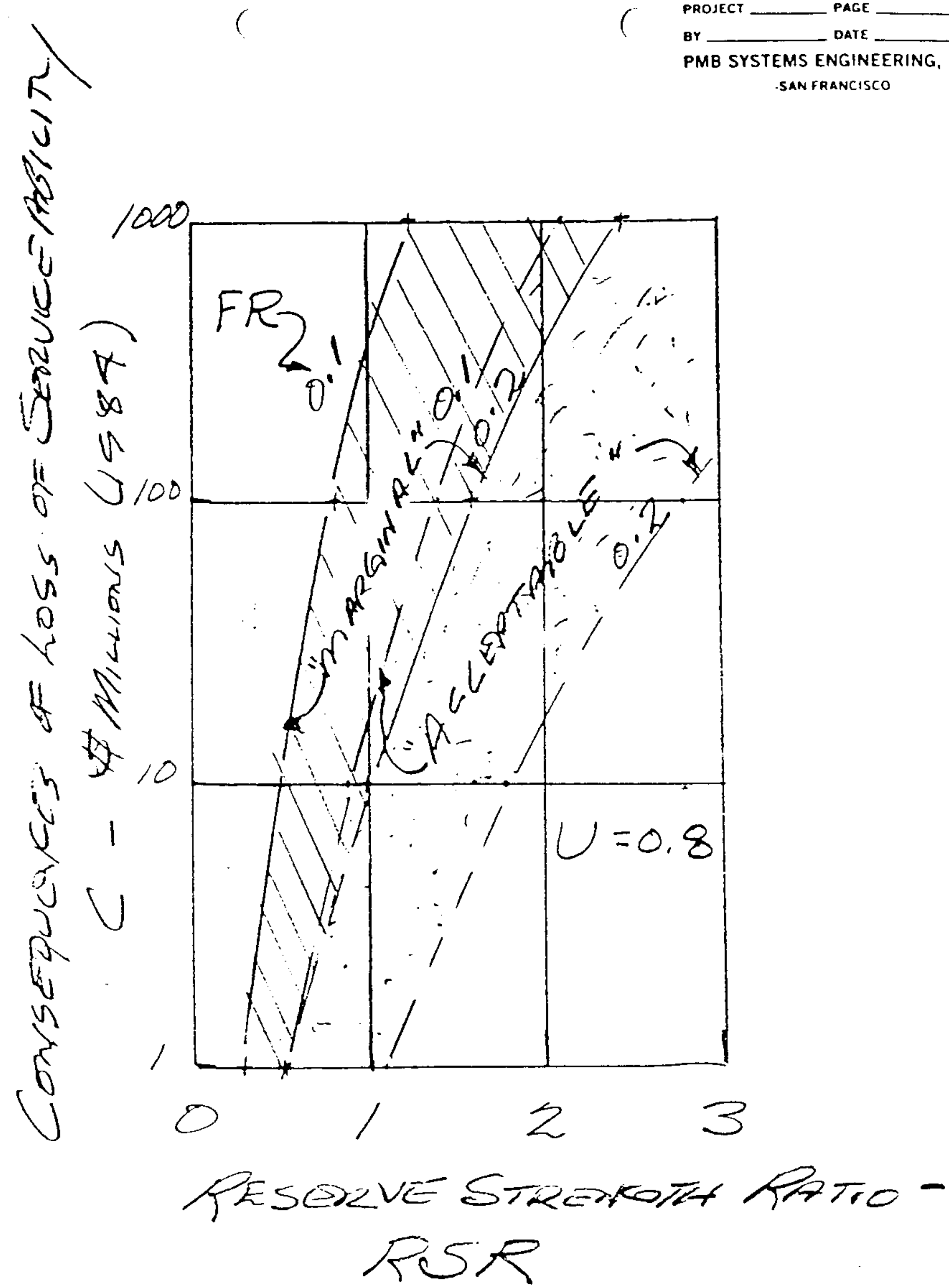
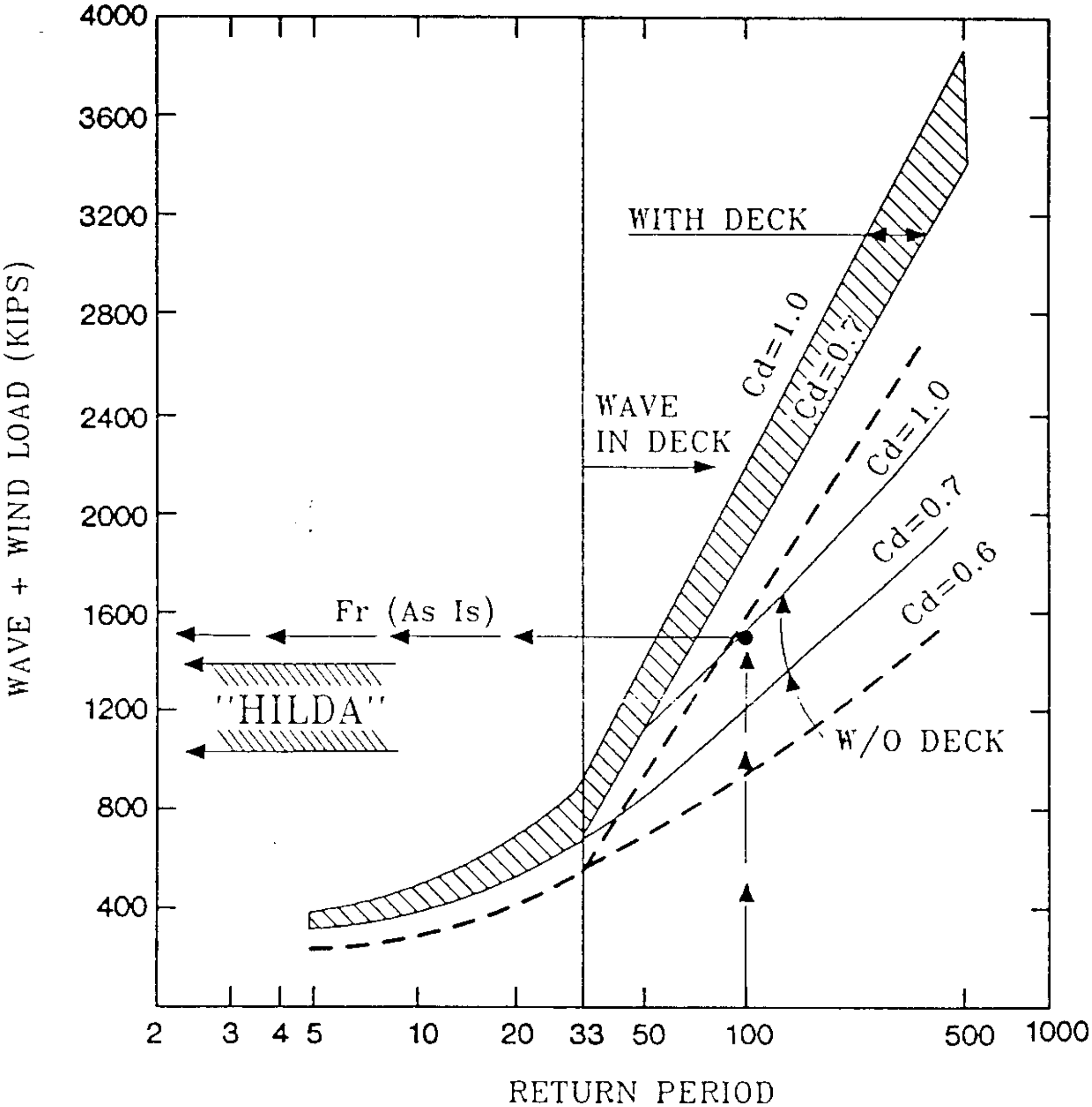


FIGURE 19



ENVIRONMENTAL FORCE VS. RETURN PERIOD – PLATFORM "A"

FIGURE 22

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RGB

GRIFF C. LEE, INC.

P.O. BOX 70787, NEW ORLEANS, LA. 70172 (504) 587-6512
(504) 282-3367

August 12, 1988

Mr. Frank Puskar
PMB Systems Engineering Inc.
500 Sansome Street
San Francisco, CA 94111

Re: AIM III Project

Dear Frank:

With reference to our recent discussion, I have reviewed the Draft of the Final Report No. 3 which was distributed to the participants by your letter of July 29. Basically, this is a very good report, adequately covering work done to take on the project. However, there are several items which I suggest you give some additonal consideration.

The last paragraph of Page 3-2 states that the RSR for typical post-1970 Gulf of Mexico platforms is in the range of 1.5. I agree that this is correct for a 1970 platform. As an example, your analysis of Platform C on Page 4-4 reported an RSR of 1.6. However, I do not agree that platforms built within the last five years would have a RSR of 1.5. In my opinion, a RSR of 2.5 would be more likely. The changes in design practices since 1970 have substantially added to the reserve strength of the structure. Considering the individual members or elements, the intended factor of safety is in the range of 1.87. When the one-third increase is allowed, this is still in the range of 1.4. It is very difficult to select member sizes so that the utilization factor is at or near 1.0. Therefore, most members have a larger factor of safety due to oversize in the selection process. Considering the entire system, the redundancy and stress redistribution increases the ultimate limit state to well over your stated 1.5. The unbraced length of deck leg is the portion of the structure with the least redundancy. However, even in this area, load redistribution will produce a RSR of over 1.5 for most typical structures. I recommend that we consider revising this paragraph. A RSR of 1.5 is below present-day practice.

In several instances in the report, as an example on Figure 5-6, it is noted that a RSR of 0.5 is "acceptable". Using Figures

4-1, 4-3, and 4-4 for reference, a RSR of 0.5 would indicate the structure will collapse during a 50-year storm - something in the order of a 60' to 65' wave. If we were to design a new platform performed today to collapse at this same wave height and used RP 2A, the design wave height would be 40' to 45', something slightly over a 5-year storm. The Report implies that a structure is "acceptable" for AIM purposes with a RSR of 0.5. However, a new platform designed for a 5-year storm would certainly be questionable. Even though the AIM project is considering repairs to older and damaged structure, this may be below a desirable minimum. I recommend that the "acceptability" be better defined or the factor 0.5 be raised.

Chapter 5 discusses three approaches to determining the acceptable range of likelihood of loss of serviceability. I question whether the "Utility" approach should be applied to manned platforms. From a technical and commercial standpoint, this approach is very well done and useful. However, from a legal standpoint, it probably should be given careful qualifications. Assume that a major catastrophe occurred to a manned platform after an AIM evaluation and that the inevitable litigation followed. During the "discovery period", all of the owner's files, records and information is available to the Plaintiff's attorney. Using the example of the utility approach on Page 6-15, it would be extremely damaging for the owner to have this information made public. The Plaintiff's attorney would win his case by explaining to the "blue collar" jury that "big oil" considered spending $30 million to $40 million to make the platform 10 times safer and elected not to do so to save money. Possibly a softer approach or some legal guidance should be considered.

Concerning the regulatory approach to the AIM process, additional discussion may be desirable. Under the new Consolidated Rules, MMS Regulations 30 CFR Part 250.142(b), the owner is required to inspect all platforms at least every five years. The results of this inspection must be reported indicating what repairs, if any, are needed. In 250.130(e), all major repairs of damage to a platform must be approved either in advance, or within 24 hours after emergency repairs. The regulator must operate under these rules and has little justification or reason for not requiring that the structure be repaired "to restore an existing permitted condition". As part of the AIM III Project, and possibly continued in AIM IV, it would be desirable to discuss reasons to allow the operator to request a variation to repair to something less than the "permitted condition". As an example, in 250.134

it is stated that the recurrence period for the design event shall not be less than 100 years for a platform designed for a 20-year service life. For existing structures which need repair and have a relatively short productive life remaining, this 5 times rule could possibly be an approach to reduce the design requirement.

One of the more important aspects developed by the AIM report, in my opinion, is the Consequence Category discussed in Chapter 3. This concept divides offshore platforms into three categories, depending upon the consequence of loss of serviceability. This concept is not currently included in MMS regulations although it might be very advantageous to the industry if it could be included. It could influence design of new platforms and relocation of existing structures as well as repairs covered by the AIM project. This would be an ideal subject to discuss at the meeting since the vehicle to influence MMS regulations is via the oil companies to the Offshore Operators Committee. Also, this concept does not appear in the design provisions of API RP 2A. However, it is being introduced in a slightly different form in the revisions recently accepted for Section 7 - Surveys, approved for the 18th Edition. Please note on the attached advanced copy of Table 7.4.2 that API is now recommending different inspection intervals based on platform classification. Please note however that the AIM and API definition of manned platforms is not the same. It would not be an impossible step to consider including this concept in the design provisions as well. However, if this is done, there could be a corresponding increase in design requirement for platforms that are manned during the extreme event.

Another concept which might be of assistance to the regulator to justify a variation would be to have a different definition for the RSR. As I understand this report, the RSR is the ratio of static collapse load to the particular design event load. In this report the RSR is calculated using current procedures to develop the design load. It might be also desirable to develop RSR's based on loads as originally designed, and possibly to alternate, if a 5 times rule or some variation were allowed.

On a more detailed level, Figures 1-4, 4-3 and 4-4 do not appear to agree. On Figure 1, for a 100-year storm Fr is approximately 1600 kips. On Figure 4-3 the 100-year storm equals a 70' wave. On Figue 4-4, the 70' wave indicates 1900 or 2100 kips. This does not seem to agree with Figure 1. Are these two results from different directions or am I misreading the curves?

August 12, 1988

The fourth paragraph of Page 6.14 lists the ULS for the Alaskan platform. Are these "as designed" or "as repaired".

To summarize, as previously stated, I think that this is an excellent report. I do not recommend a major change. My intention was to add thoughts for consideration which, hopefully, can be accomplished without a major rewrite.

Please call me when you are ready to discuss further.

Very truly yours,

Griff Lee

Griff C. Lee

GCL:am

RP 2S, - 18th Ed ~~ITEM "L"~~

RECEIVED

AUG 15 1988

PMB SYSTEMS ENGINEERING, INC.

4/11/88

PROPOSED REVISIONS TO API (RP2A) SECTION 7

SECTION 7

SURVEYS

7.1 GENERAL

During the life of the structure, in-place surveys which monitor the adequacy of the corrosion protection system and determine the condition of the structure, should be performed in order to safeguard human life and property, protect the environment, and prevent the loss of natural resources.

7.2 PERSONNEL

7.2.1 Planning

Surveys should be planned by qualified personnel possessing survey experience and technical expertise commensurate with the level of survey to be performed.

7.2.2 Survey

Surveys should be performed by competent personnel and may also include the observations of platform operating and maintenance personnel familiar with its condition. The personnel conducting surveys of above water areas should know how and where to look for damage and situations which could lead to damage.

Visual inspection of the underwater portion of a structure should be conducted by ROV or divers under the supervision of personnel experienced in the underwater visual inspection methods employed. Nondestructive examination of the structure should be performed by personnel trained and experienced in application of the method being used. Cathodic potential surveys should be supervised by personnel knowledgeable in this area.

7.3 SURVEY LEVELS

7.3.1 Level I

The effectiveness of the corrosion protection system employed should be checked and an above water visual survey should be performed annually to detect deteriorating coating systems, excessive corrosion, and bent, missing or damaged members.

This survey should identify indications of obvious overloading, design deficiencies and any use which is inconsistent with the platforms original purpose. This survey should also include a general examination of all structural members in the splash zone and above water, concentrating on the condition of the more critical areas such as deck legs, girders, trusses, etc. Nondestructive testing should be used when visual inspection cannot fully determine the extent of damage. Should the Level I survey indicate that underwater damage may have occurred, a Level II inspection should be conducted as soon as conditions permit.

7.3.2 Level II

A Level II survey consists of general underwater visual inspection by divers or ROV to detect for the presence of any or all of the following:

1. Excessive corrosion
2. Accidental or environmental overloading
3. Scour, seafloor instability, etc.
4. Fatigue damage
5. Design or construction deficiencies
6. Presence of debris
7. Excessive marine growth

The survey should include the measurement of cathodic potentials of preselected critical areas using divers or ROV. Detection of significant structural damage during a Level II survey should become the basis for initiation of a Level III survey. The Level III survey, if required, should be conducted as soon as conditions permit.

7.3.3 Level III

A Level III survey consists of an underwater visual inspection of preselected areas and/or, based on results of the Level II survey, areas of known or suspected damage. Such areas should be sufficiently cleaned of marine growth to permit thorough inspection. Pre-selection of areas to be surveyed (see Section 7.5) should be based on an engineering evaluation of areas particularly susceptible to structural damage or to areas where repeated inspections are desirable in order to monitor their integrity over time. Detection of significant structural damage during a Level III survey should become the basis for initiation of a Level IV survey in those instances where visual inspection alone cannot determine the extent of damage. The Level IV survey, if required, should be conducted as soon as conditions permit.

7.3.4 Level IV

A Level IV survey consists of underwater nondestructive testing of preselected areas and/or, based on results of the Level III survey, areas of known or suspected damage. Level IV should also include detailed inspection and measurement of damaged areas.

7.4 SURVEY FREQUENCY

7.4.1 Definitions

Manned Platform - A platform which is actually and continuously occupied by persons accommodated and living thereon. The platform may or may not be evacuated during extreme environmental conditions.

Unmanned Platform - A platform upon which persons may be employed at any one time, but upon which no living accommodations or quarters are provided. A structure that is manned for a short period of time, for such operations as extended maintenance or a limited drilling program, may be considered unmanned for survey purposes.

Well-protectors are small jacket structures with little or no process equipment and no personnel quartered onboard.

Caissons are single leg structures with little or no process equipment and no personnel quartered onboard.

7.4.2 Guideline Survey Intervals

The time interval between surveys for fixed platforms should not exceed the guideline intervals shown in Table 7.4.2., unless experience and/or engineering analyses indicate that different intervals are justified. Justification for changing guideline survey intervals should be documented and retained by the operator. In such cases, the following factors should be taken into account:

1. Consequence of failure to human life, property, the environment, and/or conservation of natural resources.
2. Manned or Unmanned platform.
3. Wells (naturally flowing, sour gas, high pressure, etc.)
4. Original design criteria.
5. Present structural condition.
6. Service history of platform (condition of corrosion protection system, results of previous inspections, changes in design operating or loading conditions, prior damage & repairs etc.).
7. Platform structural redundancy.
8. Criticality of the platform to other operations.
9. Platform location (frontier area, water depth, etc.).

Table 7.4.2

Guideline Survey Intervals

Level	I	II	III	IV
Manned	1 yr	3 thru 5 yrs.	6 thru 10 yrs.	*
Unmanned	1 yr	5 thru 10 yrs.	11 thru 15 yrs.	*
Well Protectors/Caissons	1 yr.	5 thru 10 yrs.	*	*

*Surveys should be performed as indicated in paragraphs 7.3.2 and 7.3.3

7.4.3 Special Surveys

A Level I survey should be conducted after direct exposure to a design environmental event (e.g., hurricane, earthquake, etc.). Except for caisson and well protectors, a Level II survey should be conducted upon completion of the initial drilling program. Also, a Level II survey should be conducted after severe accidental loading (e.g., boat collision, etc.).

Areas critical to the structural integrity of the platform, which have undergone structural repair, should be subjected to a Level II survey approximately one year following completion of the repair. A Level III survey should be performed when excessive marine growth prevents visual inspection of the repaired areas.

7.5 PRESELECTED SURVEY AREAS

During initial platform design and any subsequent reanalysis, critical members and joints should be identified to assist in defining requirements for future platform surveys. Selection of critical areas should be based on such factors as joint and member loads, resses, stress concentrations, structural redundancy, and fatigue lives determinined during platform design.

7.6 RECORDS

Records of all surveys should be retained by the operator for the life of the platform. Such records should contain detailed accounts of the surveys performed, including video tapes, photographs, measurements, and other pertinent survey results. Descriptions of detected damage should be thoroughly documented and included with the survey results. Any resulting repairs and engineering evaluations of the structures condition should be documented and retained.

Original File 038345
FJP
RGB

BEN C. GERWICK, INC., Consulting Construction Engineers

Ocean & Artic Construction
Marine Terminals
Deep Foundations
Prestressed Concrete

500 Sansome Street
San Francisco, CA 94111

Phone: (415) 398-8972

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August 15, 1988

RECEIVED
AUG 17 1988
PMB SYSTEMS ENGINEERING, INC

PMB Systems Engineering Inc.
500 Sansome Street
San Francisco, CA. 94111

Attention: Mr. F.J. Puskar

Subject: AIM III REPORT REVIEW

Dear Frank:

1. This is, in my opinion, an outstanding report, one of the most lucid I have ever read on this very difficult and complex subject.

2. This study and report has been based on the valuation of probable costs (risk times consequences) versus probable benefits. In the case of property, the relationship between costs and benefits is reasonably comparable, the major uncertainty on the benefit side being pricing and marketing aspects of resources produced in the future.

   We have a more difficult problem with regard to the utility aspects such as environmental and life safety. So far you've (correctly) addressed them within the current social framework of the U.S.A. However, the environmental movement is only 25 years old and is changing thru time, as well as geographically when we go to other countries. A developing country, desperately in need of cash to provide needed facilities for its burgeoning population, will place values on the environmental consequences which are orders of magnitude below ours. The same with life safety, which varies from culture to culture.

   This report is a study relevant in quantitative terms to the offshore U.S. in the year 1988. It provides mechanisms to adjust to differing valuations in future years, and to differing geographical-cultural locals.

   As such this report has significant value for consideration and application beyond the specific scope of the assignment.

3. The comprehension of the scope of the report and the relationships between chapters could be improved by adding to the Introduction, a description of each of the chapters, their contents and their relation to the overall report.

4. Section 7.0. The first sentence is not complete, ie. "...suitability for service" of what? "of existing platforms, especially those which have suffered damage in prior service."

   At the end of the present Section 7, Conclusions, I think that once again there could well be a concluding paragraph, summing up the meaning of the entire report.

5. Page 5-5 first and second paragraphs. If historically acceptable RSR's are less than 1, does this mean that if a series of hurricanes entered the northeast Gulf of Mexico, many of the older platforms would fail?

6. Figure 6-4 and text, page 6-4, bottom paragraph.

   This indicates one of the more promising ways of acceptably measuring the value of life - by addressing the amount one would pay to extend his life by ten years or to decrease the probability of death by a factor of 10.

   Since this approach is emerging in various risk-reliability studies, it may deserve an additional paragraph or two to expand upon its use.

   Perhaps this concept could be introduced in Section 5.3 or as a separate section 5.4.

7. Page 8-2, Implementation. I believe that it is not legally possible for the MMS to jointly develop a set of guidelines with an industry group such as API.

   I believe the MMS is required to do this themselves. They may however request a study and recommendations by the Marine Board.

   The other approach possible is through ANSI (American National Standards Institute) but that is a long and complex process.

   You may wish to check with MMS.

8. <u>Editiorial Corrections</u>

   A. Page 1-1, line 9. Correct spelling of "where".

   B. Page 3-6, second paragraph. The first and third sentences, while correct, are awkward and unclear.

   C. Page 4-6, Equation 9. The term "V" is not defined, (altho V_f and V_r are).

   D. Figure 5-6, Caption. Should it be "KU = 0.8" or "U=0.8". Refer to page 5-6, top paragraph.

E. Page 6-7, second (middle) paragraph, sentence beginning "Based on" is so complex as to be unclear, due to lengthy clauses and sub-clauses within parentheses.

Sincerely,

Ben Gerwick

Ben C. Gerwick, Jr.

/mt

cc: Griff Lee

((ux file ...
FJP
RGB

OXY

OXY USA INC.
1980 Post Oak Boulevard
Box 27570, Houston, TX 77227

August 16, 1988

RECEIVED
AUG 18 1988
... SYSTEMS ENGINEERING, I...

PMB Systems Engineering Inc.
500 Sansome Street
San Francisco, California 94111

Attention: Mr. F. J. Pusker

Subject: AIM III - Draft of Final Report Number 3

Gentlemen:

I have the following comments concerning the subject draft:

1) On page 3-2 the report implies that most post-1970 conventional 8-pile platforms have an RSR of about 1.5. This number seems low based on Titus and Banon's paper and other numbers I have seen. I realize that the 1.5 comes from your actual work on platform "C"; however, this platform was installed in 1969 (see page 5-9) which meant it was probably designed in 1967 or 1968. I would expect the more recent platforms to have an RSR of 1.75 to 2.25. If this is actually the case, the last paragraph on page 3-2 should be expanded to indicate more recent platforms might have a higher RSR than the 1.5 indicated by this study.

2) In Chapter 7, Figure 7-1 indicates that RSR's as low as 0.5 to 1.0 might be acceptable. I am sure that this might well be true for the suitability for service of certain in place structures under the conditions outlined in the report. I would suggest that it is appropriate to put a warning in the report that this work in no way indicates that original designs should be designed to have RSR's of 0.5 to 1.0. This might seem obvious that one should not use these conclusions as a justification for using a low RSR on an original design; however, stranger things have happened when someone just reads the conclusions of a report.

3) In Chapter 8, I am confused by the differences between the "platform requalification engineering guidelines" and the "AIM Program and platform performance and evaluation standards". Could you be more specific about the two concepts. Personally, I do not see the need for the second item if a recommended practice is developed by API and put into the rules of the MMS.

I look forward to our October 6, 1988 meeting and discussion of the above and other comments that you have received.

Sincerely,

OXY USA Inc.

T. E. Rees

T. E. Rees
Engineering Consultant
Houston District

TER:dl

FJP

Chevron

Chevron Corporation
2400 Camino Ramon, San Ramon, California
Mail Address P O Box 5045, San Ramon, CA 94583 0945

August 22, 1988

AIM-III JIP: Comments on
Draft Guidelines
Project #185106

PMB Systems Engineering, Inc.
500 Sansome Street
San Francisco, CA 94111

Attention: F. J. Puskar

Gentlemen:

Attached are some comments on your draft document, "Development of Guidelines for Evaluations and Justifications of Suitability for Service." Please consider them before finalizing the document.

Please address any questions or discussion to Scott Martindale at (415) 842-8202 or Jack Hong at (415) 842-8157.

Sincerely,

D. L. Wilson

D. L. Wilson

SGM:lw
TS850/SGM/650
Attachment

COMMENTS ON DRAFT DOCUMENT:

"DEVELOPMENT OF GUIDELINES FOR EVALUATIONS AND JUSTIFICATIONS OF SUITABILITY FOR SERVICE"

1. Our previous comments on the low intuitive appeal of RSR in the range of .1-.5 are no longer applicable because of your correction to the computational error which now brings RSR up to .5-2.4. However, some may still want to use β rather than calculate an RSR with the "uncertainties measure" U.

2. Note that static pushover probably defines the SLS rather than the ULS. More accurate ULS may be estimated with dynamic (cyclic wave) analysis.

3. Several items should be clarified, including:

   a. When referring to β, p_f, or RSR, preface with "required," "actual," or "acceptable" for easier understanding, e.g., the last paragraph on page 4-7.

   b. On the top of page 3-3, explain how earthquake-controlled RSR is computed to be in the range of 2. Obviously it's not based on a wave-profile static pushover.

   c. Show (e.g., in Appendix) or reference how the coefficients and exponents are derived in equations 13, 14, 18, 19.

   d. Note that "acceptable" RSR's less than 1.0 or 1.5 do not imply that new designs should target these values.

   e. On page 5-10 (last paragraph section 5.2.3), installation of an SSSV should reduce both ends of the cost range. Furthermore, reference 2 does not describe the economics for platform C.

   f. On page 6-4, second paragraph, note that the likelihood of serious injuries can also be reduced by reducing the chance of explosion, blowout, or fire in the event of a structural failure.

   g. On page 6-8, paragraph 4, explain more fully why Type II uncertainties can be neglected and how this improves the analysis.

03B345

U.S. Department of Transportation
United States Coast Guard

Commandant
United States Coast Guard

Washington, D.C. 20593-0001
Staff Symbol: G-MTH-3
Phone: (202) 267-2988

3903
August 23, 1988

PMB Systems Engineering Inc.
Attn: Mr. Frank J. Puskar
500 Sansome Street
San Francisco, CA 94111

Gentlemen:

In response to your letter of July 29, 1988, I have reviewed the draft AIM III Final Report.

You have done a commendable job in discussing some sensitive and hard to quantify issues related to suitability of service. One particular topic that was handled well was the assessment of personnel death and injury in terms of economic and utility values. Your illustrations of typical measures related to suitable of service were meaningful and provide useful guidance for the evaluation of suitability of service factors.

I do have one general comment related to the report. The report briefly describes the public-regulatory concerns, yet it does not include any reference to the responsibility of regulatory agencies to see that some of the more abstract and difficult issues, such as social perception and political impact, are addressed. Extreme incidents can not always be quantified as the direct consequential costs associated with the loss of a facility, loss of life, clean up, etc. Failure of a platform leading to an environmental incident could lead to closing of an entire production region, in turn leading to even greater losses than those mentioned in the report. (Which is illustrated by the recent PIPER A explosion that has lead to the temporary closing down of the entire Piper field, as well as those adjoining it.) This loss would be borne by the platform owner/operator as well as owners/operators of neighboring platforms and ultimately the public. In the most extreme cases, this could even lead to much greater cost to society, resulting from making an essential supply of a useful resource irretrievable and through the enactment of "over-reactive" costly regulations applicable to platforms operating elsewhere. These reactions may in fact be extreme and exceed any reasonable safety expectations, yet society's perception of what is appropriate may dictate what is done.

Enclosure (1) identifies comments that I have pertaining to specific items in the text.

Thank you for the opportunity to comment on the report. If you require any further assistance regarding review of this report or the comments contained herein, please call me or Mr. John Baxter at (202) 267-2988.

Sincerely,

J. S. SPENCER
Chief, Naval Architecture Branch
Marine Technical and Hazardous
Materials Division
By direction of the Commandant

Encl: (1) Comments to AIM III Draft Final Report

Comments to AIM III Draft Final Report

Page 6-4 -- I don't understand the meaning of Figure 6-2. More explanation is necessary in the text on page 6-4 to explain how this figure ties in with the evaluation of the risk-benefit relationship. I am confused as to what is meant by Benefit (Annual Expenditure) in Figure 6-2.

Page 6-4 -- Reference is made to Figure 1-2 for an illustration of judicial value. It appears that there is a typographical error here. Figure 1-2 is not appropriate. I believe that the figure you want to present is not presently in the report.

Pages 6-12 and 6-13 -- You provide good perspective on the relative proportions of structural vs non-structural accidents related to loss of serviceability. No one can say that you have not used up-to-date information, when on page 6-13 you include the July 1988 PIPER A incident as an example of a non-structural accident.

Figures 6-13 and 6-14 -- It appears that data points may be missing on these graphs along the RSR axis at the Upper Voluntary Range line (Figure 6-13) and the marginal line (Figure 6-14).

Enclosure (1)

File 036345

Shell Oil Company

Two Shell Plaza
P.O. Box 2099
Houston, Texas 77001

August 24, 1988

PMB Systems Engineering Inc.
Attn.: Mr. F. J. Puskar
500 Sansome Street
San Francisco, CA 94111

Dear Mr. Puskar:

SUBJECT: AIM III - DRAFT OF FINAL REPORT

Attached you will find a copy of our markups/comments on the draft of the final AIM III report. In general we feel more explanation needs to be supplied on how to use the data contained there-in. In addition, the standard probability symbols should be utilized to avoid confusion. All figures should contain a little more information, i.e., definitions of terms, examples, directions, etc. This report should be something any normal engineer could use with full explanations on the limitations of each alternative approach.

Please let me know if you have any questions on the markups or comments.

Very truly yours,

K. A. Digre
Sr. Staff Civil Engineer

KAD:SPT

Attachment

cc: F. P. Dunn
P. W. Marshall
J. R. Red-Horse

RECEIVED
AUG 26 1988
PMB SYSTEMS ENGINEERING, INC.

NOTE: SHELL DID A THOROUGH JOB REVIEWING & COMMENTING ON THE DRAFT REPORT. THIS INCLUDES CALLOUTS OF TYPOGRAPHICAL ERRORS AND ERRORS IN CALCULATIONS. WE HAVE ONLY INCLUDED THE MOST IMPORTANT COMMENTS IN THIS APPENDIX. WE APPREZIATE SHELL'S EXCELLENT REVIEW!
PMB.

Platforms designed for locations in which earthquakes control or dominate the design forces commonly have RSR's ~~in the range~~ of About 2 [8,9].

The RSR should be viewed not as a single number, but as the best estimate within a given range of potential RSR's [10,11]. This is due to the uncertainties and variabilities that are associated with analytical evaluations of the performance of elements (joints, braces, legs, piles, as is, repaired, etc.) and a system of elements (the platform) [12].

It should be understood that the RSR is an index for comparing a type of analytical evaluation of ultimate limit state (ULS) capacities of platforms (e.g. based on static push-over analyses and static behavior of elements). In general, the true ULS capacity can not be directly or easily equated with the capacity used to define the RSR. The RSR is intended to provide a practical, yet realistic, basis on which to compare platform AIM programs and make judgements concerning suitability for service.

Add some WORDS

Care must be taken when interpreting RSR's when the F_r occurs with waves just below deck level. In these cases large RSR will be obtained but any increase in wave height would greatly increase loading

Another important aspect of the RSR pertains to the reference force, F_r. This reference force is intended to reflect present-day consensus on what force should be used to design an equivalent new platform. There are two critical aspects imbedded in F_r. The first is the basis for determination of the force; the basis is intended to represent a minimum level of force that the "community" (consensus of engineers, operators, owners, regulators) deems prudent for design of equivalent new platforms.

The second is that the basis for design presumed is the present Working Stress Design (WSD) guidelines of API RP 2A [4]. Structural analyses founded primarily on linear elastic methods are the basis of these guidelines. Other bases for design (e.g. Limit State and Load and

If it is assumed that the demands (loads) placed on and the ~~capabilities~~ capacities (resistance) inherent to a given platform are lognormally distributed then the expected value of

4.1 RSR and Likelihood of Loss of Serviceability

The RSR can be related to the likelihood of the platform loss of serviceability $\boxed{(P_f)}$ as follows [11]:

Is this probability of failure?

Use TRUE not a ie β & σ though!

$$\cancel{RSR = FR\exp(BU)} \qquad E[RSR] = F_R\, e^{(\beta\sigma)} \tag{2}$$

~~FR~~ F_R is a force ratio:

if so! say so!

$$F_R \; \cancel{FR} = \frac{\bar{F}}{F_r} \tag{3}$$

Where $\bar{F}$ is the median annual expected maximum force on the platform, and F_r is the reference force.

β ~~B~~ is the Safety Index, and ~~U~~ σ is the Standard Deviation of the natural Logs of the force and resistance probability distributions (demands and capacities are assumed to be Lognormally distributed).

combined total uncertainty of the

Put at the beginning!

Why does AIM program enter into this

σ ~~U~~ is a measure of the uncertainties in the demands (loads) and capacities (resistances) of a given platform and AIM program. Note that ~~U~~ σ can be directly influenced by data gathering, inspections, and other measures taken to reduce the uncertainties and variabilities associated with loadings and resistances.

This the entire basis of this derivation!

The Safety Index, ~~B~~ β, can be related to the likelihood of the platform loss of serviceability, P_f, to a good approximation (~~B~~ β = 2 to 4) as follows [11]:

$$P_f = 0.475\exp(-B^{1.6}) \tag{4}$$

A ~~B~~ β of 3 implies a P_f of about 0.1 percent (10^{-3}). A ~~B~~ β of 4 implies a P_f of about 0.01 percent (10^{-4}).

entered into the characterizations of return periods (a measure of uncertainty) associated with the maximum loadings [10,11]. It is advisable to determine P_f with and without these uncertainties so that the effects of potential improvements in the evaluations of conditions and forces can be understood.

A numerical example will help to clarify these developments. In AIM-III, it was found that platform "C" had ~~a~~ API minimum reference force, F_r = 1630 kips ~~(API minimum)~~. The site and platform specific oceanographic-hydrodynamic study indicated a median ANNUAL force, $\hat{F}$ = 280 kips (Figure 4-1). Thus, F_R ~~FR~~ = 0.17.

state which direction is RSR same in both directions?

The probability distribution σ_f of forces indicates a Standard Deviation of the Log of total forces, U_f = 0.74. As will be described in detail later, if the additional uncertainties due to prediction of wave heights [*], wave forces [*], and platform capacities [* , *] are considered, σ ~~U~~ = 0.77. If it is presumed that the acceptable ~~B~~ β = 3.0, then equation (2) indicates a required RSR = 1.7.

Platform "C" had an RSR of about 1.6 (Figure 4-2). Given the presumed ~~B~~ β, platform "C" has close to an acceptable RSR.

Acceptable β for API-LRFD is lifetime not annual however 0.1%/YR is reasonable also β = 2 for remaining lifetime

* MISSING REFS WILL BE CITED IN FINAL REPORT

important!

The Standard Deviations of demand, U_f, and capacity, U_r, are determined from their respective COV's (equations 10 and 11), and the resultant U determined as follows:

HOW ?

$$U = [U_f^2 + U_r^2]^{1/2} \tag{12}$$

For example, AIM platform "C" had a V_h = 0.38, α = 2.0, and an estimated V_{cf} = 0.30 (Figure 4-6). From equation (10), V_f = 0.82. Based on previous analyses [10,11,12], V_r is estimated to be 0.3 (Figure 4-7).

From equations (9) and (12), the uncertainty measure, U = 0.77.

Thus, we can see that the RSR can be directly related with indices of platform likelihood of loss of serviceability (P_f or B) and uncertainties in the demands (loads) and capacities (resistances) of a platform. Next, measures of likelihood of loss of serviceability will be related to ranges of potential consequences associated with the loss of serviceability.

$(.76)^2 + (.30)^2 =$

?

$\downarrow$

$(.82)^2 + (.30)^2 = (.87)^2$

$\sqrt{\ln(1+.87^2)} = .76 = \alpha V_h$

effect of professional uncertainty has been understated → zero? why?

This reduction is not appropriate if lognormal U_j ($\sigma_{\ln x}$) used to start with

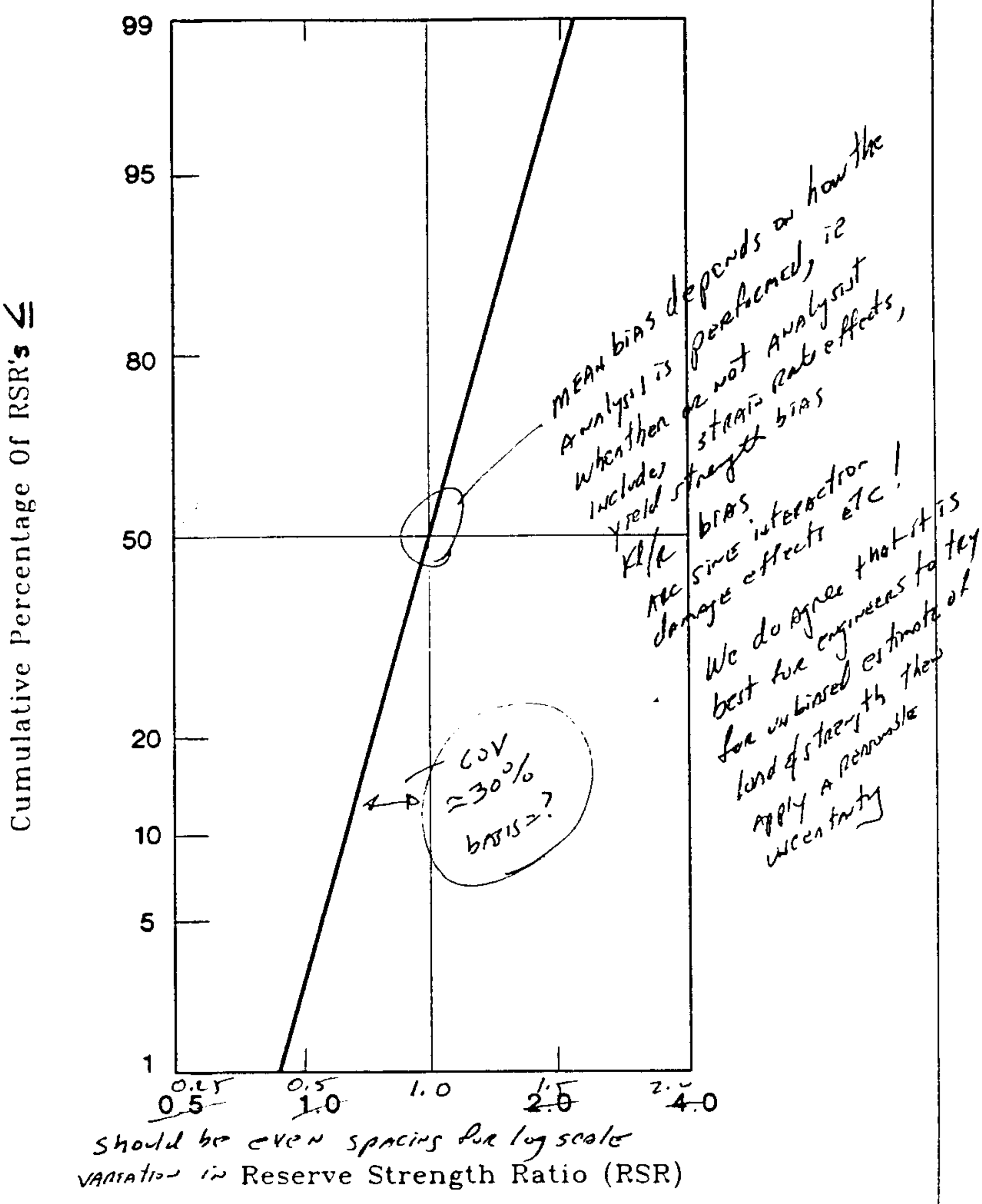

Figure 4-7 Evaluation of Inherent and Modeling Uncertainties Associated With the Determination of the Platform Ultimate Limit State Capacity and RSR

in the range of 0.3 to 0.1 percent per year, and consequences to fall in the range of $1 to $10 millions (Category 1), and $10 millions to $50 millions (Category 2).

Given a likelihood of loss of serviceability in the range of 0.3 to 0.1 percent per year, the Safety Index (annual), β = 2.76 to 3.11 (equation 4).

For the shallow water and moderate water depth platforms studied in AIM-II and III, the Force Ratios could be estimated to be approximately 0.2 (shallow and moderate water depth platforms with high decks) [2,18].

Based on evaluations of the uncertainties associated with loadings and capacities of Gulf of Mexico platforms [10,11,15], U (equation 12) is estimated to be in the range of 0.6 to 0.8. Evaluations of the uncertainties associated with the AIM example platforms indicates values in the range of 0.7 to 0.8 (higher uncertainties associated with older, defective, repaired structures).

Where is this from ?

Given the Safety Index range of 2.76 to 3.11, the Force Ratio range of 0.1 to 0.2, and the loading-capacity uncertainty range of 0.6 to 0.8, RSR = 0.5 to 2.4 (equation 2).

It could be contended that only natural or inherent variability uncertainties should be recognized when analyses are based on actuarial or historical data on platform failures. This is because the failure events do not involve engineering or modeling uncertainties. Consideration of only the inherent uncertainties would indicate U to be in the range of 0.3 to 0.4.

how do we know

SHAKY LOGIC

1/2 ?

We prefer a life time β of 2 for monitary risk (corresponds to annual β of 3 for new platforms with 25 yr life)
This would allow higher annual risk for structures with short remaining life (not applicable to human safty risks)

$$PVF = \frac{1-(1+r)^{-L}}{r} \tag{17}$$

For long L's and replacements in the event of loss of serviceability: PVF = 1/r.

For short L's and low net investment rates, PVF = L.

Note for the cases of non-replacement of structures whose serviceability has been lost, and deferred revenues considered, more complex PVF's will need to be considered [16].

Also, it should be noted that the exposure period for the platform is defined as the present AIM cycle period, L. It is not defined as the total expected life of the structure. This is because of the presumed continuous updating and upgrading implied in AIM requalification programs over the life of the platform. It is in this way that the length of the AIM cycle enters the decision concerning the optimum or desirable AIM program for a platform at a given point in time. At this stage, no attempt is made to project the future outcomes or developments of AIM cycles.

Do not Agree! Loading risk is still the same. This works for fatigue — not overloads!

Also is one paragraph!

One of the concerns with the expected value utility analysis is that the multiplication of low likelihoods of loss of serviceability (Pf) and costs of potential future losses (F) can give unreasonably low weighting to the possible implications of losses of platform serviceability. A second related concern is that the quantitative assessments of the likelihoods of loss of platform serviceability are not dependable enough to base decisions upon.

The expected value of an AIM decision alternative is the average monetary result per decision that would be realized if the decision maker accepted the alternative over a series of identical repeated trials. The expected value concept is a philosophy for consistent decision making, which, if practiced consistently can bring the sum total of the utilities of the decisions to the highest possible level. The expected value is not an absolute measure of a monetary outcome. It is incorrect to believe that the expected value is the most probable result of selecting an alternative.

Relative to the second concern with the quantitative evaluations of likelihoods of loss of serviceability, they must be reasonable and realistic. It should be remembered that these quantitative evaluations are being used in a comparative sense, one AIM alternative versus another. Consistency in the methods used to develop, interpret, and apply the likelihoods is a primary requirement.

The last point with these concerns is that if the decision makers believe that the consequences of loss of serviceability are not being given their proper weighting, then an alternative decision making process known as "Utility Theory" [20,21,22] can be applied to recognize the risk-consequence characteristics of the decision makers.

Figure does not back-up statement — Cost curve is for new construction

Given that the costs associated with the AIM alternatives that determine the platform reliability are related linearly to the log of the probability of loss of serviceability (Figure 5-15), the Safety Index (annual) which produces the lowest combination of expected initial costs and potential future losses resulting from platform loss of serviceability, β_0, can be determined as [11,16]:

lifetime or annual in original references!

$$\beta_o = \left[-\ln \frac{0.915}{(PVF)(CR)} \right]^{0.625} \quad (18)$$

$\beta = 1.7$ for $CR \times PVF = 10$

this works if cost vs risk is continuous — not a step function which is more likely in our situations!!

Where CR is the cost ratio: the ratio of the expected cost of the platform loss of serviceability to the cost needed to decrease the likelihood of the platform loss of serviceability by a factor of 10.

Given the best or optimum (from an expected cost standpoint) Safety Index, B_0, the associated RSR can be determined from equation (2).

For example, platform "A's" likelihood of loss of serviceability could be decreased by a factor of 10 by raising the decks. For a projected loss of serviceability cost of \$3.3 million (non-replacement) [2], and a cost of raising the decks of \$1 million, CR = 3.3.

We prefere a direct comparison of cost vs risk vs number juggling and approximation

Assuming PVF = 2, equation (18) would indicate a best AIM alternative Safety Index, B_0 = 1.53. Based on a Force Ratio, FR = 0.13, and an Uncertainty measure U = 0.8, the Safety Index of 1.53 would equate to a best alternative AIM program RSR = 0.44. The platform (as is, without raised decks) had an RSR = 0.62, thus, the proposed AIM program would develop an RSR that would exceed that indicated to be the best based on an expected cost evaluation. Note Fig 5-14 says plat 'A' is unacceptable! which should be used.

The product of the Cost Ratio, CR, and the Present Value Function, PVF (= L for short AIM cycles), can be interpreted as a measure of Consequences, C, associated with a platform's loss of serviceability. Equations (18) and (2) can be used to define the RSR's associated with the Consequences measure for different values of Force Ratios and Uncertainty measures (Figure 5-16).

The data for the three AIM platforms discussed earlier in this section have been plotted in Figure 5-16.

cost-benefit evaluation of this North Sea platform ranged from 0.5 to 1.5 percent per year (minimum cost points, Figure 5-15). These likelihoods translate to Safety Indices of 2.6 to 2.2. Given FR = 0.6 and U = 0.3, the RSR's (Equation 2) = 1.2 ("marginal") to 1.3 ("acceptable"). The cost-benefit evaluation based RSR's are in the same range as those from the parallel consideration of potential serious injuries to operating personnel.

Marshall [25] has pursued a similar experience based approach to evaluate the implications of potential serious injuries in determining platform reliability (Figure 6-15). Actuarial data on the number of serious injuries per incident and the rates of occurrence of those numbers has been compiled for a wide variety of activities and structure/facility operations. Two general categories of activities were evaluated, voluntary and involuntary. Broad bands were drawn to relate the categories of activities to the numbers of injuries to the likelihood of these injuries. Note that the likelihoods are based on a one-year exposure time to the activity or hazard of concern.

NO - RISKS WE IMPOSE ON OUR WORKERS should be consistent with the "involuntary" band

If one were to evaluate the platform operating personnel exposure as voluntary, and bracket the numbers of potential serious injuries defined by coal mining (20 to 30 serious injuries per incident) and commercial aircraft activities (80 to 120 serious injuries per incident), the likelihood of platform loss of serviceability would be about 1 percent. Given the North Sea platform example, this risk rate would translate to a B = 2.33, and RSR = 0.6 exp (2.33 x 0.3) = 1.2. This result is very comparable with those shown in Figures 6-13 and 6-14.

The Canadian Standards Association (CSA) has issued guidelines for the development of limit state design for offshore platforms [29]. These

APPENDIX B

DERIVATION OF LOWEST TOTAL COST ALTERNATIVE

SAFETY INDEX (Bo) FORMULATION (EQUATION 18)

$$E[C] = E[I] + E[F] \qquad \text{(Equation 15)}$$

$$E[F] = [F](PVF)(P_f) \qquad \text{(Equation 16)}$$

but

$$[PF] = [F](PVF)$$

$$E[C] = E[I] + [PF](P_f)$$

Differentiate with respect to P_f to find zero slope (Figure 5-15)

$$\frac{dE[C]}{dP_f} = \frac{dE[I]}{dP_f} + [PF] + P_f \frac{d[PF]}{dP_f} = 0$$

$$\frac{d[PF]}{dP_f} = 0$$

Therefore,

$$\frac{dE[I]}{dP_f} = -[PF]$$

$$C[I] = C \operatorname{Log}_{10} P_f + C_o \qquad \text{(Figure 5-15)}$$

C_o = Intercept of Initial Cost Curve

C = Slope of Initial Cost Curve

$$\frac{dE[I]}{dP_f} = -\frac{C}{(2.3)P_f} \qquad \mathrm{Ln}_e 10 = 2.3$$

Therefore,

$$\frac{C}{(2.3)P_f} = [PF]$$

or

$$P_{fo} = \frac{C}{(2.3)[PF]} = \text{probability of failure for lowest total cost point}$$

$$P_{fo} = 0.475\exp(-B_o^{1.6}) \qquad \text{(Equation 4)}$$

$$B_o = \left[-\ln\frac{P_{fo}}{0.475}\right]^{\frac{1}{1.6}}$$

$$B_o = \left[-\ln\frac{0.915}{\frac{[PF]}{C}}\right]^{0.625}$$

Recall

$$[PF] = [F](PVF)$$

Let

$$CR = \frac{[F]}{C}$$

Thus

$$B_o = \left[-\ln \frac{0.915}{(PVF)(CF)}\right]^{0.625} \qquad \text{(Equation 18)}$$